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PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

#12

In re the Application of

Koji SHIGEMATSU

Group Art Unit: 2851

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Application No.: 09/722,506

Examiner: H. Nguyen

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Docket No.: 105192.01

For: PROJECTION OPTICAL SYSTEM AND EXPOSURE APPARATUS AND METHOD

SUBMISSION OF ACCURATE TRANSLATION OF PRIORITY DOCUMENT

Director of the U.S. Patent and Trademark Office
Washington, D.C. 20231

Sir:

Further to the October 24, 2002 Amendment, Applicant submits the attached accurate translation of the priority application (i.e., Japanese Patent Application No. 10-024043 filed January 22, 1998 in Japan) for the above-identified U.S. Patent application.

Applicant submits that the submission of the attached accurate translation of the priority documents perfects Applicant's foreign priority.

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Respectfully submitted,

Klifton L. Kime

Mario A. Costantino
Registration No. 33,565

Klifton L. Kime
Registration No. 42,733

MAC:KLK/dmw
Date: November 13, 2002

OLIFF & BERRIDGE, PLC
P.O. Box 19928
Alexandria, Virginia 22320
Telephone: (703) 836-6400

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[Document] Specification

[Title of the Invention] PROJECTION OPTICAL SYSTEM, EXPOSURE APPARATUS PROVIDED WITH THE OPTICAL SYSTEM, AND DEVICE MANUFACTURING METHOD

[Scope of the Claims]

[Claim 1]

A projection optical system which projects an image of a pattern on a first object onto a second object, comprising:

in order from the first object,

a first lens group having a positive refractive power,

a second lens group having a negative refractive power,

a third lens group having a positive refractive power,

a fourth lens group having a negative refractive power, and

a fifth lens group having a positive refractive power;

wherein a position at which a light beam that enters the projection optical system parallel to an optical axis of the projection optical system from the second object side on a near axis crosses the optical axis is between the fourth lens group and the fifth lens group,

the fourth lens group has at least one aspherical surface,

the fifth lens group has an aperture stop which determines a numerical aperture inside the fifth lens group,

the fourth or fifth lens group has at least one aspherical surface which is arranged at any position between the aspherical surface of the fourth lens group and the aperture stop,

the fifth lens group has at least one aspherical surface which is arranged between the aperture stop and the second object side, and

when a distance between the first object and the second object is L,

a distance on the optical axis from the position crossing the optical axis between the fourth and fifth lenses to the aperture stop is d, and

a numerical aperture of a light beam exiting toward the second object side from the projection optical system is N.A.,

the following condition is satisfied;

$0.01 < d / \{L \times (1 - N.A.)\} < 0.4$ (1).

[Claim 2]

The projection optical system as set forth in claim 1,

wherein the aperture stop is a variable aperture stop, and

the aperture stop is arranged between the crossing position between the fourth and fifth lens groups and the second object side so that, when the numerical aperture of the light beam exiting from the projection optical system to the second object side is changed by the aperture stop, the difference of the numerical aperture of the light beam which reaches inside the projection region on the second object which is generated by vignetting of the aperture stop is minimized.

[Claim 3]

The projection optical system as set forth in claim 1 or 2,

wherein at least one aspherical surface of the fourth lens group is a concave surface, and the aspherical surface has a shape such that a refractive power of a peripheral part of the

aspherical surface is weaker than a diffractive power of the aspherical surface in the vicinity of the optical axis,

at least one of the [at least one] aspherical surface of the fourth or fifth lens group that is at any position between the aspherical surface and the aperture stop has

a shape such that the refractive power of a peripheral part of the aspherical surface is weaker than the refractive power of the aspherical surface in the vicinity of the optical axis when the aspherical surface is a convex surface, and

a shape such that the refractive power of the peripheral part of the aspherical surface is stronger than the refractive power of the aspherical surface in the vicinity of the optical axis when the aspherical surface is a concave surface,

at least one of the [at least one] aspherical surface of the fifth lens group that is provided between the aperture stop and the second object side has

a shape such that the refractive part of a peripheral part of the aspherical surface is weaker than the refractive power of the aspherical surface in the vicinity of the optical axis when the aspherical surface is a convex surface, and

a shape such that the refractive power of the peripheral part of the aspherical surface is stronger than the refractive power of the aspherical surface in the vicinity of the optical axis when the aspherical surface is a concave surface.

[Claim 4]

A projection optical system which projects an image of a pattern on a first object onto a second object, comprising:

a first lens group arranged between the first and second objects and having a positive refractive power,

a second lens group arranged between the first lens group and the second object and having a positive power,

a third lens group arranged between the second lens group and the second object and having a positive refractive power,

a fourth lens group arranged between the third lens group and the second object and having a negative refractive power,

a fifth lens group arranged between the fourth lens group and the second object and having a positive refractive power, and

an aperture stop arranged between the fourth lens group and the second object and which determines a numerical aperture,

wherein on a near axis, a light beam that enters the projection optical system parallel to the optical axis of the projection optical system from the second object side crosses the optical axis between the fourth and fifth lens groups,

a first aspherical surface of a concave shape is arranged in the fourth lens group,

a second aspherical surface is arranged between the first aspherical surface and the second object,

a third aspherical surface is arranged between the aperture stop and the second object,

the first aspherical surface has a shape such that a refractive power of a peripheral part of the first aspherical surface is weaker than a refractive power of the first aspherical surface in the vicinity of the optical axis,

the second aspherical surface has

a shape such that a refractive power of a peripheral part of the second aspherical surface is weaker than a refractive power of the second aspherical surface in the vicinity of the optical axis when the second aspherical surface is a convex surface, and

a shape such that the refractive power of the peripheral part of the second aspherical surface is stronger than the refractive power of the second aspherical surface in the vicinity of the optical axis when the second aspherical surface is a concave surface, and

the third aspherical surface has

a shape such that the refractive power of the peripheral part of the third aspherical surface is weaker than the refractive power of the third aspherical surface in the vicinity of the optical axis when the third aspherical surface is a convex surface, and

a shape such that the refractive power of the peripheral part of the third aspherical surface is stronger than the refractive power of the third aspherical surface in the vicinity of the optical axis when the third aspherical surface is a concave surface.

[Claim 5]

The projection optical system as set forth in any of claims 1-4,

wherein the first lens group has at least one aspherical surface.

[Claim 6]

The projection optical system as set forth in any of claims 1-5,

wherein the second lens group has at least one aspherical surface.

[Claim 7]

The projection optical system as set forth in any of claims 1-6,

wherein the third lens group has at least one aspherical surface.

[Claim 8]

The projection optical system as set forth in any of claims 1-7,

wherein when a focal length of the first lens group is f1, a focal length of the second lens group is f2, a focal length of the third lens group is f3, a focal length of the fourth lens group is f4, a focal length of the fifth lens group is f5, and a distance between the first object and the second object is L, the following conditions are satisfied:

$0.05 < f1 / L < 0.5$ (2)

$0.02 < -f2 / L < 0.2$ (3)

$0.04 < f3 / L < 0.4$ (4)

$0.03 < -f4 / L < 0.3$ (5)

$0.04 < f5 / L < 0.4$ (6).

[Claim 9]

An exposure apparatus, comprising:

a first stage which supports a mask as the first object,

an illumination optical system which illuminates the mask,

a second stage which holds a substrate as the second object, and

the projection optical system as set forth in any of claims 1-8,

wherein an image of a pattern of the mask which has been illuminated by the illumination optical system is formed on the substrate by the projection optical system.

[Claim 10]

A method of manufacturing a semiconductor device using the exposure apparatus as set forth in claim 9, comprising the steps of :

coating a photosensitive material onto the substrate,

projecting an image of a pattern of the mask onto the substrate via the projection optical system,

developing the photosensitive material on the substrate, and

forming a predetermined circuit pattern onto the substrate using the developed photosensitive material as a mask.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

This invention relates to an exposure apparatus which is provided with a projection optical system which projects an image of a pattern of a first object onto a second object and the projection optical system and is used when a mask pattern is transferred onto a substrate during a lithography process which manufactures a semiconductor element, a liquid crystal display element, or the like and a method of manufacturing a device (a semiconductor element, an imaging element, a liquid crystal display element, a thin film magnetic head, or the like) using the exposure apparatus.

[0002]

[Prior Art]

Conventionally, in order to manufacture a semiconductor element or the like, a batch exposure type or scanning exposure type projection exposure apparatus is used. In a batch exposure type projection exposure apparatus which is known as a stepper or the like, an image of a pattern of a reticle as a mask is transferred onto a wafer, a glass plate, or the like coated by a resist via a projection optical system. Additionally, in a scanning exposure type projection exposure apparatus, a step and scan method is used. Recently, as fineness of a pattern of a

semiconductor integrated circuit or the like has been developed, an optical characteristic of a projection optical system provided with such an exposure apparatus, particularly resolution is demanded to be improved.

[0003]

In order to improve resolution of a projection optical system, shortening of an exposure wavelength or making a numerical aperture (N.A.) larger can be considered. With respect to a wavelength of an exposure light beam, a g line (λ=436 nm) of a mercury lamp through an i line (λ=365 nm) are mainly used. More recently, it has been attempted to use a light source emitting a short wavelength of light, for example, an excimer laser (λ=248 nm, 193 nm). Because of this, a projection optical system having an optical characteristic which can be used along with a short wavelength of exposure light has been developed.

[0004]

Furthermore, in a projection optical system, along with the improvement of resolution, demands for reduction of image distortion have further intensified. Here, "image distortion" can include distortion (distortion aberration) originating in a projection optical system, image distortion generated by warping or the like of a wafer which is exposed on an image side of a projection optical system, and image distortion which is generated by warping of a reticle on which a circuit pattern or the like is drawn on an object side of a projection optical system. Furthermore, recently, fineness of a transfer pattern has been more developed, and reduction of image distortion is also further demanded.

[0005]

In order to reduce the effects of wafer warping on image distortion, a so-called image side telecentric optical system is conventionally used, which locates an exit pupil position on an

image side of a projection optical system at a far distance. Meanwhile, with respect to the reduction of image distortion because of reticle warping as well, a so-called object side telecentric optical system is considered, which locates an entrance pupil position of a projection optical system at a distance further from an object plane, and various proposals have been made with respect to an optical system which locates an entrance pupil position of a projection optical system at a distance relatively further from an object plane. For example, a projection optical system which thus locates an entrance pupil position of a projection optical system at a distance further from an object plane is disclosed in, for example, Japanese Laid-Open Patent Applications 63-118115, 4-157412, and 5-173065.

[0006]

Furthermore, in a projection optical system which projects and exposes a pattern on a reticle onto a wafer, when a plurality of lens surfaces are constituted by aspherical surface shapes, it is possible to reduce the number of lenses to be used. With respect to this type of technology, a projection optical system is disclosed in, for example, Japanese Laid-Open Patent Applications 1-316709, 5-334593, and 7-128592.

[0007]

Furthermore, in a recent process of manufacturing a semiconductor element, a liquid crystal display element, or the like, according to various use conditions and patterns on a reticle, selection and use of a more optimal numerical aperture is demanded. Therefore, in an exposure apparatus as well, a projection optical system having a stop which can vary a numerical aperture is demanded.

[0008]

[Problems to be Resolved by This Invention]

As described above, in order to reduce the effects of reticle and wafer warping on image distortion, it is desirable that a projection optical system is made to be telecentric on an image side and on an object side. Because of this, the optical system which is disclosed in the above-mentioned applications is a so-called both-side telecentric projection optical system in which an object side and an image side are both telecentric. However, it is difficult for the above-mentioned conventional both-side telecentric projection optical system to sufficiently increase a numerical aperture (N.A.) which contributes to resolution by reducing various aberrations in a large projection area, and distortion is not sufficiently corrected; therefore, there are problems.

[0009]

Furthermore, when a variable aperture stop is arranged in order to vary a numerical aperture of a projection optical system, if the numerical aperture of this variable aperture stop is changed, there are cases that the effects of vignetting is generated in the peripheral part of a projection region of an image plane due to spherical aberration in a pupil. Because of this, in the peripheral part of the projection region of the image plane, at the time of varying the numerical aperture, telecentricity and illumination uniformity on an image plane are deteriorated, and a projection region cannot be sufficiently made large; therefore, there are problems.

[0010]

Furthermore, an optical system using an aspherical surface disclosed in the above-mentioned applications uses an aspherical surface in order to improve transmittance by making the overall thickness of a glass material of an optical system thin. Because of this, there is a problem that a large exposure region and a sufficiently large numerical aperture cannot be obtained. This invention reflects on the above-mentioned problems, and an object of this invention is to provide a small projection optical system with high performance capability in

which, when both-side telecentricity exists and a numerical aperture (N.A.) is varied, an aperture stop which achieves a sufficiently small effect of vignetting is provided, and by using an aspherical lens surface, various aberrations, particularly distortion, are suitably corrected while ensuring a sufficiently large numerical aperture and a large exposure region.

[0011]

Furthermore, another object of this invention is to provide an exposure apparatus provided with the projection optical system and a method of manufacturing a semiconductor device using the exposure apparatus.

[0012]

[Means of solving the problem]

In order to accomplish the above-mentioned object, in the projection optical system as set forth in claim 1,

a projection optical system PL which projects an image of a pattern on a first object R onto a second object W, comprising:

in order from the first object R,

a first lens group G1 having a positive refractive power,

a second lens group G2 having a negative refractive power,

a third lens group G3 having a positive refractive power,

a fourth lens group G4 having a negative refractive power, and

a fifth lens group G5 having a positive refractive power;

wherein a position Q at which a light beam that enters the optical system PL parallel to an optical axis AX of the projection optical system PL from the second object W side on a near axis crosses the optical axis AX is between the fourth lens group G4 and the fifth lens group G5,

the fourth lens group G4 has at least one aspherical surface ASP1,

the fifth lens group G5 has an aperture stop AS which determines a numerical aperture inside the fifth lens group,

the fourth or fifth lens group G4, G5 has at least one aspherical surface ASP2 which is arranged at any position between the aspherical surface ASP1 of the fourth lens group G4 and the aperture stop AS,

the fifth lens group G5 has at least one aspherical surface ASP3 which is arranged between the aperture stop AS and the second object W side, and

when a distance between the first object and the second object is L,

a distance on the optical axis from the position Q crossing the optical axis AX between the fourth and fifth lenses G4, G5 to the aperture stop AS is d, and

a numerical aperture of a light beam exiting toward the second object W side from the projection optical system PL is N.A.,

the following condition is satisfied;

$0.01 < d / \{L \times (1 - N.A.)\} < 0.4$ (1).

[0013]

In the above-mentioned structure, the first lens group G1 maintains telecentricity and mainly contributes to distortion correction. The second lens group G2 and the fourth lens group G4 mainly contribute to correction of Petzval's sum and have a function which accomplishes flatness of an image plane. Furthermore, the third lens group G3 generates positive distortion along with the first lens group G1 and plays a role of correcting negative distortion generated in the second lens group G2, the fourth lens group G4, and the fifth lens G5. Additionally, the third lens group G3 and the second lens group G2 have a structure of a telephoto system having

positive and negative refractive power arrangement as seen from the second object side. Because of this, this has a function which prevents the entire projection optical system PL from becoming larger. Furthermore, the fifth lens group G5 controls generation of distortion in a state particularly in which generation of spherical aberration is avoided in order to sufficiently correspond to higher numerical aperture on the second object W side, guides a light beam onto the second object W, and plays a role of imaging.

[0014]

In addition, by arranging at least one aspherical surface ASP1 in the fourth lens group G4, it is possible to control the generation of aberration, particularly coma in a sagittal direction, related to an image angle which tends to remain in a bright (high numerical aperture) optical system which is constituted by only spherical surfaces of a dioptric system. Furthermore, it is preferable that the aspherical surface is concave and an aspherical shape which weakens refraction in the vicinity of the lens.

[0015]

Furthermore, in the fourth lens group G4 and the fifth lens group G5, an aspherical surface ASP2 is arranged from the aspherical surface ASP1 to the aperture stop AS, and in the fifth lens group G5, the aspherical surface ASP3 is arranged from the aperture stop AS2 to the second object W side.

[0016]

In the fourth lens group G4 and the fifth lens group G5, the aspherical surface ASP2 is arranged from the aspherical surface ASP1 to the aperture stop AS, and in the fifth lens group G5, the aspherical surface ASP3 is arranged from the aperture stop to the second object W side; therefore, aberration can be corrected by the aspherical surface before and after the aperture stop

AS, and without deteriorating distortion and coma, high-order spherical aberration can be corrected.

[0017]

Furthermore, when the distance between the first object R and the second object W is L, the distance on the optical axis between the position Q crossing the optical axis between the fourth and fifth lenses and the aperture stop AS is d, and the numerical aperture on the second object W side of the projection optical system PL is N.A., the following condition equation (1) should be satisfied:

$0.01 < d / \{L \times (1 - N.A.)\} < 0.4$ (1).

Here, with respect to the direction which is measured between the position Q and the second object W side is positive.

[0018]

The condition equation (1) easily makes both sides telecentric and regulates a condition which minimizes an effect of vignetting within the projection region. When the upper limit of the condition equation (1) is exceeded, the aberration of the pupil becomes too large, and it becomes difficult to obtain a telecentric optical system on the both sides of the first object R and the second object W, and this is not preferable. On the contrary, when the lower limit of the condition equation (1) is exceeded, the aberration of the pupil is corrected more than needed so that Petzval's condition is made closer to 0, so the projection optical system becomes too large, and this is not preferable.

[0019]

Furthermore, preferably the projection optical system of claim 2,

wherein the aperture stop AS is a variable aperture stop, and

the aperture stop AS is arranged between the crossing position Q between the fourth and fifth lens groups G4, G5 and the second object W side so that, when the numerical aperture N.A. of the light beam exiting from the projection optical system PL to the second object W side is changed by the aperture stop AS, the difference of the numerical aperture N.A. of the light beam which reaches inside the projection region on the second object W which is generated by vignetting of the aperture stop AS is minimized.

[0020]

Here, the case is considered when a parallel light beam enters from the second object W side to the projection optical system PL. Within the parallel light beam, the light beam on a near axis (near axis chief ray) crosses the optical axis AX at a predetermined position Q by a refractive operation of a positive lens arranged on the second object W side. At that time, the positive lens on the second object W side has a positive refractive power, so the parallel light beam that enters the projection optical system PL at a predetermined angle with respect to the optical axis AX is imaged at a position shifted to the second object W side from the imaging position Q of the parallel light beam that enters along the optical axis AX on the near axis. Because of this, if the aperture stop AS is arranged between the second object W side and the position Q at which the chief ray (near axis chief ray) on the near axis crosses the optical axis AX, even if vignetting of the aperture stop AS is changed, the effects of vignetting in the peripheral part of the projection region by an imaging surface curvature of a pupil, i.e., the difference of the numerical aperture between light beams reaching each point of the projection region which is generated by shading (eclipse) of the light beam by the aperture stop AS can be practically sufficiently controlled, and various aberrations can also be corrected preferably.

[0021]

Additionally, preferably the projection optical system as set forth in claim 3,

wherein at least one aspherical surface ASP1 of the fourth lens group G4 is a concave surface, and the aspherical surface ASP1 has a shape such that a refractive power of a peripheral part of the aspherical surface ASP1 is weaker than a diffractive power of the aspherical surface ASP1 in the vicinity of the optical axis AX,

at least one of the [at least one] aspherical surface ASP2 of the fourth or fifth lens group G4, G5 that is at any position between the aspherical surface ASP1 and the aperture stop AS has

a shape such that the refractive power of a peripheral part of the aspherical surface ASP2 is weaker than the refractive power of the aspherical surface ASP2 in the vicinity of the optical axis AX when the aspherical surface ASP2 is a convex surface, and

a shape such that the refractive power of the peripheral part of the aspherical surface ASP2 is stronger than the refractive power of the aspherical surface ASP2 in the vicinity of the optical axis AX when the aspherical surface ASP2 is a concave surface,

at least one of the [at least one] aspherical surface ASP3 of the fifth lens group G5 that is provided between the aperture stop AS and the second object W side has

a shape such that the refractive part of a peripheral part of the aspherical surface ASP3 is weaker than the refractive power of the aspherical surface ASP3 in the vicinity of the optical axis AX when the aspherical surface ASP3 is a convex surface, and

a shape such that the refractive power of the peripheral part of the aspherical surface ASP3 is stronger than the refractive power of the aspherical surface ASP3 in the vicinity of the optical axis AX when the aspherical surface is a concave surface. Here, the refractive power in the peripheral part closest to the aspherical surface can also be returned slightly to the direction of the refractive power in the vicinity of the optical axis.

[0022]

Furthermore, in the projection optical system as set forth in claim 4, a projection optical system PL which projects an image of a pattern on a first object R onto a second object W, comprising:

a first lens group G1 arranged between the first and second objects R, W and having a positive refractive power,

a second lens group G2 arranged between the first lens group G1 and the second object W and having a positive power,

a third lens group G3 arranged between the second lens group G2 and the second object W and having a positive refractive power,

a fourth lens group G4 arranged between the third lens group G3 and the second object W and having a negative refractive power,

a fifth lens group G5 arranged between the fourth lens group G4 and the second object W and having a positive refractive power, and

an aperture stop AS arranged between the fourth lens group G4 and the second object W and which determines a numerical aperture,

wherein on a near axis, a light beam that enters the projection optical system PL parallel to the optical axis AX of the projection optical system PL from the second object W side crosses the optical axis AX between the fourth and fifth lens groups G4, G5,

a first aspherical surface ASP1 of a concave shape is arranged in the fourth lens group G4,

a second aspherical surface ASP2 is arranged between the first aspherical surface ASP1 and the second object W,

a third aspherical surface ASP3 is arranged between the aperture stop AS and the second object W,

the first aspherical surface ASP1 has a shape such that a refractive power of a peripheral part of the first aspherical surface ASP1 is weaker than a refractive power of the first aspherical surface ASP1 in the vicinity of the optical axis AX,

the second aspherical surface ASP2 has

a shape such that a refractive power of a peripheral part of the second aspherical surface ASP2 is weaker than a refractive power of the second aspherical surface ASP2 in the vicinity of the optical axis AX when the second aspherical surface ASP2 is a convex surface, and

a shape such that the refractive power of the peripheral part of the second aspherical surface ASP2 is stronger than the refractive power of the second aspherical surface ASP2 in the vicinity of the optical axis AX when the second aspherical surface ASP2 is a concave surface, and

the third aspherical surface ASP3 has

a shape such that the refractive power of the peripheral part of the third aspherical surface ASP3 is weaker than the refractive power of the third aspherical surface ASP3 in the vicinity of the optical axis AX when the third aspherical surface ASP3 is a convex surface, and

a shape such that the refractive power of the peripheral part of the third aspherical surface ASP3 is stronger than the refractive power of the third aspherical surface ASP3 in the vicinity of the optical axis AX when the third aspherical surface ASP3 is a concave surface.

[0023]

Furthermore, in this invention, if the aspherical surface is arranged in the first, second and third lens groups G1, G2, and G3, respectively, other than the fourth and fifth lens groups G4 and G5, respectively, this is effective for the aberration correction, so this is preferable.

[0024]

Because of this, preferably, in the projection optical system as set forth in claim 5, wherein the first lens group G1 has at least one aspherical surface ASP4. If the aspherical surface is arranged in the first lens group G1, mainly distortion aberration can be corrected.

[0025]

Furthermore, preferably, in the projection optical system as set forth in claim 6, wherein the second lens group G2 has at least one aspherical surface. If the aspherical surface is arranged in the second lens group G2, mainly the aberration of entrance pupil (shifting of the entrance pupil corresponding to an object height) can be minimized.

[0026]

Additionally, preferably, in the projection optical system as set forth in claim 7, wherein the third lens group G3 has at least one aspherical surface. If the aspherical surface is arrange in the third lens group G3, mainly coma can be corrected.

[0027]

Furthermore, in the projection optical system as set forth in claim 8, the following condition equation (2) can be satisfied:

$0.05 < f1 / L < 0.5$ (2).

[0028]

Here, f1 is a focal length of the first lens group G1, and L is a length between the first object R and the second object W. The condition equation (2) regulates a range of the optimal

refractive power of the first lens group G1. When the upper limit of the condition equation (2) is exceeded, positive distortion generated in the first lens group G1 cannot correct negative distortion generated in the second, fourth, and fifth lens groups G1, G2 and G5 **[sic. G2, G4, and G5]**, so this is not preferable. On the contrary, when the lower limit of the condition equation (2) is exceeded, this causes higher-order positive distortion, so this is not preferable.

[0029]

Furthermore, in the projection optical system as set forth in claim 8, the following condition equation (3) can be satisfied:

$0.02 < -f2 / L < 0.2$ (3).

[0030]

Here, f2 shows a focal length of the second lens group G2. The condition equation (3) establishes a range of the optimal refractive power of the second lens group G2. When the upper limit of the condition equation (3) is exceeded, Petzval's sum is insufficiently corrected, and it becomes difficult to accomplish flatness of an image plane, so this is not preferable. Meanwhile, if the lower limit of the condition equation (3) is exceeded, the generation of the negative distortion becomes large, and it is difficult to preferably correct large negative distortion in the first and third lens groups G1 and G3, respectively, and this is not preferable.

[0031]

Furthermore, in the projection optical system as set forth in claim 8, the following condition equation (4) can be satisfied:

$0.04 < f3 / L < 0.4$ (4).

[0032]

Here, f3 shows a focal length of the third lens group G3. The condition equation (4) regulates a range of the optimal refractive power of the third lens group G3. When the upper limit of the condition equation (4) is exceeded, a telephoto ratio of a telephoto system formed by the second and third lens groups G2 and G3, respectively, becomes large, so the projection optical system becomes large. Furthermore, the generating amount of the positive distortion generated in the third lens group G3 becomes small, and the negative distortion generated in the second, fourth, and fifth lens groups G2, G4 and G5, respectively, cannot be preferably corrected, so this is not preferable. On the contrary, when the lower limit of the condition equation (4) is exceeded, higher-order spherical aberration is generated, so a preferable imaging performance capability cannot be obtained on the second object, and this is not preferable.

[0033]

In addition, in the projection optical system as set forth in claim 8, the following condition equation (5) can be satisfied:

$0.03 < -f4 / L < 0.3$ (5).

[0034]

Here, f4 shows a focal length of the fourth lens group G4. The condition equation (5) regulates a range of the optimal refractive power of the fourth lens group G4. When the upper limits of the condition equation (5) is exceeded, Petzval's condition cannot be sufficiently corrected, and deterioration of flatness of an imaging plane occurs; therefore, this is not preferable. On the contrary, the lower limit of the condition equation (5) is exceeded, this generates higher order spherical aberration and, therefore, this is not preferable.

[0035]

In addition, in the projection optical system as set forth in claim 8, the following condition equation (6) can be satisfied:

$0.04 < f5 / L < 0.4$ (6).

[0036]

Here, f5 shows a focal length of the fifth lens group G5. The condition equation (6) regulates a range of the optimal refractive power of the fifth lens group. If the upper limit of the condition equation (6) is exceeded, the refractive power of the entire fifth lens group G5 becomes too weak, and as a result, the projection optical system becomes too large; therefore, this is not preferable. On the contrary, if the lower limit of the condition equation (6) is exceeded, high-order spherical aberration is generated, and the contrast of the image on the second object deteriorates; therefore, this is not preferable.

[0037]

Furthermore, the exposure apparatus as set forth in claim 9, comprising:

a first stage RS which supports a mask as the first object,

an illumination optical system IS which illuminates the mask R,

a second stage WS which holds a substrate as the second object, and

the projection optical system PL as set forth in any of claims 1-8,

wherein an image of a pattern of the mask R which has been illuminated by the illumination optical system IS is formed on the substrate W by the projection optical system PL.

[0038]

The above-mentioned exposure apparatus is provided with the projection optical system as set forth in any of claims 1-8, so the both sides can be made telecentric with a large numerical aperture; therefore, high resolution can be obtained, and projection magnification (zoom) does

not change even if warping of mask and/or substrate is generated. Therefore, exposure can be performed with high resolution without any image deformation. Furthermore, a large exposure region can be obtained, so a large chip pattern can be exposed all at once.

[0039]

Furthermore, the method of manufacturing the device as set forth in claim 10,

coating a photosensitive material onto the substrate W,

projecting an image of a pattern of the mask R onto the substrate W via the projection optical system PL,

developing the photosensitive material on the substrate W, and

forming a predetermined circuit pattern onto the substrate W using the developed photosensitive material as a mask.

[0040]

A device circuit pattern with high resolution and less image deformation can be formed on a substrate W by the method of manufacturing a device.

[0041]

[Embodiments]

The following explains embodiments of this invention based on the attached drawings. In Fig. 1, this invention is applied to a projection optical system of a projection exposure apparatus. In Fig. 1, on an object plane of a projection optical system PL, a reticle R is arranged as a projection original in which a predetermined circuit pattern is formed, and on an image plane of the projection optical system PL, a wafer W coated with a photoresist is arranged as a substrate. The reticle R is held on a reticle stage RS, the wafer W is held on a wafer stage WS,

and an illumination optical system IS which uniformly illuminates the reticle R is arranged above the reticle R.

[0042]

The projection optical system PL has a variable aperture stop AS in the vicinity of a pupil position and is substantially telecentric on the reticle R side and the wafer W side. The illumination optical system IS is constituted by an exposure light source formed by a KrF excimer laser light source, a fly eye lens which uniforms an illumination distribution of an exposure light beam of a wavelength of 248.4 nm from the light source, an illumination system aperture stop, a variable field stop (reticle blind), a condenser lens system, or the like. In addition, as an exposure light beam, a wavelength of 193 nm of ArF excimer laser light, a high frequency wave of a YAG laser beam, and i line (λ=365 nm) of a mercury lamp, or the like can also be used. The exposure light beam supplied from the illumination optical system IS illuminates the reticle R, an image of the light source within the illumination optical system is formed in the pupil position of the projection optical system PL, and so-called Koehler illumination is performed. Furthermore, the image of the pattern of the reticle R in which Koehler illumination has been performed is reduced at a zoom via the projection optical system PL and projected and exposed (transferred) onto the wafer W.

[0043]

(First Embodiment)

The following explains a projection optical system according to a first embodiment. An exposure wavelength in this embodiment is 248.4 nm. Fig. 2 is a cross-sectional view showing a lens structure of a projection optical system of the first embodiment. In Fig. 2, a projection optical system is constituted by, in order from a reticle R (object plane) as a first object, a first

lens group G1 having a positive refractive power, a second lens group G2 having a negative refractive power, a third lens group G3 having a positive refractive power, a fourth lens group G4 having a negative refractive power, and a fifth lens group G5 having a positive refractive power.

[0044]

Furthermore, the projection optical system is made telecentric on both the reticle R (object plane) side and the wafer W (image plane) side as a second object.

[0045]

Furthermore, in the projection optical system of Fig. 2, on a near axis, a position Q in which a light beam parallel to the optical axis AX that enters the optical system PL from the wafer W side crosses the optical axis AX exists between the fourth and fifth lens groups G4 and G5, respectively, and the aperture stop AS having a variable mechanism is arranged between the wafer W side and the position Q. Because of this, the difference of vignetting on the entire surface of the exposure region on the wafer W can be minimized.

[0046]

In addition, the aspherical surface ASP1 is arranged within the fourth lens group G4, the aspherical surface ASP2 is arranged between the aspherical surface ASP1 and the aperture stop AS of the wafer W side, and the aspherical surface ASP3 is arranged between the aperture stop AS within the fifth lens group G5 and the wafer W side.

[0047]

Numerical values of the projection optical system of the first embodiment are shown in Tables 1-4. Here, D0 shows a distance on the optical axis between the reticle R (first object) and the lens surface of the first lens group G1 closest to the reticle R side, WD is a distance (working

distance) on the optical axis between the wafer W and the lens surface of the fifth lens group G5 closest to the wafer W (second object) side, β is a projection magnification (zoom) of the projection optical system, N.A. is a numerical aperture of the wafer W side of the projection optical system, ϕEX is a diameter of a round exposure region (projection region) on the wafer W surface of the projection optical system, and L is a distance on the optical axis between the object images (between the reticle R and the wafer W). Furthermore, in Table 2, No. is an order of the lens surfaces from the reticle R (first object) side, r is a radius of curvature of the lens surfaces, d is an interval on the optical axis between the lens surface and the next lens surface, and n is an index of refraction for a glass material at a wavelength of 246 nm. For example, fluorite can be used as a glass material.

[0048]

Furthermore, Table 3 shows aspherical coefficients showing the shapes of aspherical surfaces ASP1, ASP2 and ASP3. The aspherical equation can be shown as follows.

$$Z = \frac{ch^2}{1+\sqrt{\left[1-(1+\kappa)c^2h^2\right]}} + Ah^4 = Bh^6 + Ch^8 + Dh^{10} + Eh^{12} + Fh^{14}$$

Here, Z shows a sagittal amount of a surface parallel to the optical axis, c is a curvature on the top of the surface, h is a distance from the optical axis, and κ is a conical coefficient. A, B, C, D, E, and F show aspherical surface coefficients. Furthermore, the aspherical equation is used in the same manner in all embodiments.

[0049]

Furthermore, condition corresponding values are listed in Table 4. Furthermore, in Table 4, f1 shows a focal length of the first lens group G1, f2 shows a focal length of the second

lens group G2, f3 is a focal length of the third lens group G3, f4 is a focal length of the fourth lens group G4, and f5 is focal length of the fifth lens group G5. In addition, d shows a distance on the optical axis between the aperture stop AS within the fifth lens group G5 and the position Q in which the light beam parallel to the optical axis AX that enters the projection optical system PL from the wafer W side crosses the optical axis AX.

[0050]

In the same manner as the above-mentioned aspherical surface equation, symbols for the numerical values or the like for all embodiments are the same as in the above-mentioned first embodiment.

[0051]

If the maximum value of the numerical aperture of the wafer W side of the projection optical system of the first embodiment is 0.8, and the variable range of the numerical aperture is approximately 60% of the maximum value, the variable range of the numerical aperture according to the aperture stop AS is $0.5 \leq$ N. A. ≤ 0.8.

[0052]

[Table 1]

Numbers for the First Embodiment

D0=	56.938
WD=	8.558
β=	¼
Maximum N.A.=	0.8
Φ EX=	26.4
L=	1189.996

[0053]

[Table 2]

No.	r	d	n	
1	-255.627	13.000	1.50839	
2	306.419	8.567	1	
3	1565.905	26.363	1.50839	
4	-286.322	1.000	1	
5	828.381	24.476	1.50839	
6	-314.474	1.000	1	
7	332.392	29.451	1.50839	
8	-407.364	1.000	1	
9	271.626	17.000	1.50839	
10	204.642	6.844	1	
11	311.458	31.538	1.50839	
12	-295.797	1.000	1	
13	-2000.000	12.436	1.50839	
14	152.723	25.832	1	
15	-224.897	12.000	1.50839	
16	194.016	23.075	1	
17	-228.159	12.500	1.50839	
18	750.000	29.560	1	
19	-125.249	18.000	1.50839	
20	-456.292	6.197	1	
21	-316.444	29.551	1.50839	
22	-168.563	1.000	1	
23	∞	40.572	1.50839	
24	-267.422	1.000	1	
25	2178.298	44.226	1.50839	
26	-317.500	1.000	1	
27	309.182	47.253	1.50839	
28	-1355.659	1.000	1	
29	171.033	46.299	1.50839	
30	475.084	20.092	1	
31	465.958	20.807	1.50839	
32	118.116	46.763	1	
33	-211.023	12.000	1.50839	(ASP1)
34	186.008	44.783	1	
35	-120.544	12.850	1.50839	
36	∞	11.955	1	
37	-477.419	39.938	1.50839	(ASP2)
38	-169.642	4.108	1	
39	∞	8.892	1	(Q)
40	684.757	40.830	1.50839	
41	-391.691	0.000	1	
42	∞	9.043	1	(AS)
43	1500.000	49.893	1.50839	
44	-274.486	12.401	1	
45	-214.316	27.250	1.50839	
46	-282.306	10.000	1	
47	260.941	40.402	1.50839	
48	1227.057	1.000	1	
49	188.000	39.918	1.50839	
50	444.771	1.000	1	
51	178.000	29.205	1.50839	
52	308.876	1.000	1	
53	149.162	33.190	1.50839	
54	476.624	3.871	1	(ASP3)
55	613.189	24.077	1.50839	
56	65.511	6.493	1	
57	66.070	60.000	1.50839	
58	367.843	(WD)	1	

[0054]

[Table 3]

Aspherical Coefficients

Aspherical Coefficients of ASP1	
c=	-4.73883E-04
κ=	1.212633
A=	-1.37869E-08
B=	3.11693E-12
C=	5.04656E-17
D=	6.46573E-22
E=	-3.20804E-25
F=	1.66371E-29
Aspherical Coefficients of ASP2	
c=	2.09459E-03
κ=	-0.419761
A=	-3.03031E-09
B=	-3.82761E-13
C=	4.92647E-18
D=	-1.27524E-21
E=	1.11209E-25
F=	-4.75978E-30
Aspherical Coefficients of ASP3	
c=	2.09809E-03
κ=	0
A=	6.78816E-09
B=	9.68697E-13
C=	-5.23581E-17
D=	1.18829E-21
E=	0
F=	0

[0055]

[Table 4]

Condition Corresponding Values for the First Embodiment

(1)	$0.084 \le d/\{L \times (1 - N.A.)\} \le 0.209$
(2)	f1/L=0.125
(3)	-f2/L=0.046
(4)	f3/L=0.102
(5)	-f4/L=0.079
(6)	f5/L=0.109

f1= 148.730
f2= -54.952
f3= 120.942
f4= -93.589
f5= 129.783
L= 1189.996
d= 49.722
N.A.= 0.8~0.5

[0056]

Fig. 3 shows vertical aberrations of the projection optical system of the first embodiment. Fig. 4 shows horizontal aberrations (coma) in the tangential direction and the sagittal direction. In each aberration diagram, N.A. shows a numerical aperture of the wafer W side of the projection optical system, Y shows an image height on the wafer W side. In the astigmatism diagram, the broken lines show tangential image planes, and solid lines show sagittal image planes. Furthermore, in aberration diagrams in all embodiments, the same symbols are used in the same manner as in the first embodiment.

[0057]

As is clear from each aberration diagram, with respect to the projection optical system of the first embodiment, particularly distortion is preferably corrected in the entire large exposure region, and other aberrations are also corrected in a well-balanced manner. Furthermore, even if both sides of the projection optical system of the first embodiment is telecentric, the maximum value of the numerical aperture is 0.8 which is large, and the effects of vignetting is less. Even when the numerical aperture is changed to be large, each aberration can be preferably corrected.

[0058]

(Second embodiment)

The following explains a structure of the projection optical system of a second embodiment. An exposure wavelength for this example is also 248.4 nm. Fig. 5 is a cross-sectional view showing a lens structure of a projection optical system of the second embodiment. In Fig. 5, a projection optical system is constituted by, in order from a reticle R (object plane) as a first object, a first lens group G1 having a positive refractive power, a second lens group G2 having a negative refractive power, a third lens group G3 having a positive refractive power, a fourth lens group G4 having a negative refractive power, and a fifth lens group G5 having a positive refractive power.

Furthermore, the projection optical system is made telecentric on both the reticle R (object plane) side and the wafer W (image plane) side as a second object.

[0059]

Furthermore, in the projection optical system of Fig. 5, on a near axis, a position Q in which a light beam parallel to the optical axis AX that enters the optical system from the wafer W side crosses the optical axis AX exists between the fourth and fifth lens groups G4 and G5, respectively, and the aperture stop AS having a variable mechanism is arranged on the wafer W side from the position Q. Because of this, the difference of vignetting on the entire surface of the exposure region on the wafer W can be minimized.

[0060]

In addition, the aspherical surface ASP1 is arranged within the fourth lens group G4, the aspherical surface ASP2 is arranged between the aspherical surface ASP1 and the aperture stop

AS of the wafer W side, and the aspherical surface ASP3 is arranged between the aperture stop AS within the fifth lens group G5 and the wafer W side.

[0061]

Furthermore, the aspherical surface ASP4 is arranged within the first lens group G1. Numerical values of the projection optical system of the second embodiment are listed in Tables 5-8. Furthermore, in the same manner as in the projection optical system of the first embodiment, for example, fluorite can be used for a glass material.

[0062]

If the maximum value of the numerical aperture of the wafer W side of the projection optical system of the second embodiment is also 0.8, and the variable range of the numerical aperture is approximately 60% of the maximum value, the variable range of the numerical aperture according to the aperture stop AS is 0.5 ≤ N. A. ≤ 0.8.

[0063]

[Table 5]

Numbers for the Second Embodiment

D0=	56.937
WD=	8.556
β=	1/4
Maximum N.A.=	0.8
ΦEX=	26.4
L=	1190.293

[0064]

[Table 6]

No.	r	d	n	
1	-255.794	13.000	1.50839	
2	304.711	8.549	1	(ASP4)
3	1523.076	26.352	1.50839	
4	-290.961	1.000	1	
5	707.183	24.451	1.50839	
6	-337.153	1.000	1	
7	342.978	29.211	1.50839	
8	-406.487	1.000	1	
9	262.194	17.000	1.50839	
10	192.603	6.830	1	
11	282.569	31.441	1.50839	
12	-296.721	1.000	1	
13	-2000.000	12.774	1.50839	
14	156.410	25.862	1	
15	-217.396	12.000	1.50839	
16	193.187	23.071	1	
17	-229.962	12.500	1.50839	
18	753.548	29.591	1	
19	-125.018	18.000	1.50839	
20	-470.631	6.215	1	
21	-322.848	29.532	1.50839	
22	-168.545	1.000	1	
23	∞	40.488	1.50839	
24	-267.922	1.000	1	
25	2058.177	44.221	1.50839	
26	-319.862	1.000	1	
27	308.013	47.495	1.50839	
28	-1379.214	1.000	1	
29	171.065	46.313	1.50839	
30	475.356	20.101	1	
31	465.085	20.822	1.50839	
32	118.145	46.805	1	
33	-210.732	12.000	1.50839	(ASP1)
34	186.081	44.774	1	
35	-120.565	12.850	1.50839	
36	∞	11.978	1	
37	-477.987	39.928	1.50839	(ASP2)
38	-169.679	4.102	1	
39	∞	8.911	1	(Q)
40	682.568	40.816	1.50839	
41	-391.897	0.000	1	
42	∞	9.070	1	(AS)
43	1500.000	49.868	1.50839	
44	-274.701	12.416	1	
45	-214.373	27.250	1.50839	
46	-282.422	10.000	1	
47	260.913	40.405	1.50839	
48	1226.772	1.000	1	
49	188.000	39.907	1.50839	
50	444.503	1.000	1	
51	178.000	29.185	1.50839	
52	308.504	1.000	1	
53	149.159	33.191	1.50839	
54	474.418	3.897	1	(ASP3)
55	612.596	24.177	1.50839	
56	65.478	6.451	1	
57	66.000	60.000	1.50839	
58	368.643	(WD)	1	

[0065]

[Table 7]

Aspherical Coefficients

Aspherical Coefficients of ASP4	
c=	3.28179E-03
κ=	0
A=	-3.81013E-09
B=	2.15522E-13
C=	7.31492E-18
D=	-1.31012E-21
E=	0
F=	0
Aspherical Coefficients of ASP1	
c=	-4.74536E-03
κ=	1.223505
A=	-1.41105E-08
B=	3.15056E-12
C=	5.33738E-17
D=	6.14925E-22
E=	-3.11253E-25
F=	1.59082E-29
Aspherical Coefficients of ASP2	
c=	-2.09211E-03
κ=	-0.445417
A=	-2.99871E-09
B=	-3.87784E-13
C=	4.85381E-18
D=	-1.27131E-21
E=	1.09975E-25
F=	-4.70926E-30
Aspherical Coefficients of ASP3	
c=	2.10785E-03
κ=	0
A=	6.70585E-09
B=	9.66412E-13
C=	-5.16458E-17
D=	1.16221E-21
E=	0
F=	0

[0066]

[Table 8]

Condition Corresponding Values for the First Embodiment

(1)	$0.084 \leq d/\{L \times (1 - N.A.)\} \leq 0.209$
(2)	f1/L=0.125
(3)	-f2/L=0.046
(4)	f3/L=0.101
(5)	-f4/L=0.079
(6)	f5/L=0.109

f1=	148.873
f2=	-54.783
f3=	120.796
f4=	-93.618
f5=	129.808
L=	1190.293
d=	49.726
N.A.=	0.8~0.5

[0067]

Fig. 6 shows vertical aberrations of the projection optical system of the second embodiment. Fig. 7 shows horizontal aberrations (coma) in the tangential direction and the sagittal direction.

[0068]

As is clear from each aberration diagram, with respect to the projection optical system of the second embodiment as well, particularly distortion is preferably corrected in the entire large exposure region, and other aberrations are also corrected in a well-balanced manner. Furthermore, even if both sides of the projection optical system of the second embodiment is telecentric, the maximum value of the numerical aperture is 0.8 which is large, and the effects of vignetting is less. Even when the numerical aperture is changed to be large, each aberration can be preferably corrected.

[0069]

(Third Embodiment)

The following explains a structure of a projection optical system according to a third embodiment. An exposure wavelength in this embodiment is also 248.4 nm. Fig. 8 is a cross-sectional view showing a lens structure of a projection optical system of the third embodiment. In Fig. 8, a projection optical system is constituted by, in order from a reticle R (object plane) as a first object, a first lens group G1 having a positive refractive power, a second lens group G2 having a negative refractive power, a third lens group G3 having a positive refractive power, a fourth lens group G4 having a negative refractive power, and a fifth lens group G5 having a positive refractive power.

[0070]

Furthermore, the projection optical system is made telecentric on both the reticle R (object plane) side and the wafer W (image plane) side as a second object.

[0071]

Furthermore, in the projection optical system of Fig. 8, on a near axis, a position Q in which a light beam parallel to the optical axis that enters the optical system PL from the wafer W side crosses the optical axis AX exists between the fourth and fifth lens groups G4 and G5, respectively, and the aperture stop AS having a variable mechanism is arranged on the wafer W side from the position Q. Because of this, the difference of vignetting on the entire surface of the exposure region on the wafer W can be minimized.

[0072]

In addition, the aspherical surface ASP1 is arranged within the fourth lens group G4, the aspherical surface ASP2 is arranged between the aspherical surface ASP1 and the aperture stop AS of the wafer W side, and the aspherical surface ASP3 is arranged between the aperture stop

AS within the fifth lens group G5 and the wafer W side. Furthermore, the aspherical surface ASP4 is arranged in the second lens G2.

[0073]

Numerical values of the projection optical system of the third embodiment are listed in Tables 9-12. Furthermore, in the same manner as in the projection optical system of the first embodiment, for example, fluorite can be used for a glass material.

[0074]

If the maximum value of the numerical aperture of the wafer W side of the projection optical system of the third embodiment is also 0.8, and the variable range of the numerical aperture is approximately 60% of the maximum value, the variable range of the numerical aperture according to the aperture stop AS is 0.5 ≤ N. A. ≤ 0.8.

[0075]

[Table 9]

Numbers for the Third Embodiment

D0=	56.947
WD=	7.678
β=	1/4
Maximum N.A.=	0.8
Φ EX=	26.4
L=	1191.307

[0076]

[Table 10]

No.	r	d	n	
1	-295.194	13.000	1.50839	
2	307.090	11.543	1	
3	2094.974	20.585	1.50839	
4	-308.498	1.000	1	
5	798.586	25.527	1.50839	
6	-348.935	1.000	1	
7	421.955	28.789	1.50839	
8	-335.489	1.000	1	
9	281.085	17.000	1.50839	
10	210.236	3.852	1	
11	248.819	31.665	1.50839	
12	-312.999	1.000	1	
13	-2000.000	12.729	1.50839	
14	150.843	27.217	1	
15	-203.928	12.000	1.50839	
16	167.173	26.604	1	
17	-208.236	12.500	1.50839	
18	957.666	24.946	1	(ASP4)
19	-147.060	18.000	1.50839	
20	-378.007	7.483	1	
21	-258.912	25.237	1.50839	
22	-168.885	1.000	1	
23	∞	40.270	1.50839	
24	-266.905	1.000	1	
25	1909.000	44.411	1.50839	
26	-318.771	1.000	1	
27	281.823	48.046	1.50839	
28	-2703.904	1.000	1	
29	173.110	46.118	1.50839	
30	491.765	23.296	1	
31	475.493	20.366	1.50839	
32	120.322	46.663	1	
33	-209.981	12.000	1.50839	(ASP1)
34	197.000	45.464	1	
35	-114.299	12.850	1.50839	
36	-5000.000	11.908	1	
37	-478.278	42.997	1.50839	(ASP2)
38	-169.870	4.260	1	
39	∞	8.837	1	(Q)
40	683.041	40.543	1.50839	
41	-386.391	0.000	1	
42	∞	8.716	1	(AS)
43	1378.469	47.021	1.50839	
44	-287.893	17.279	1	
45	-214.067	27.250	1.50839	
46	-277.449	10.000	1	
47	260.145	42.695	1.50839	
48	1760.879	1.000	1	
49	189.250	38.807	1.50839	
50	444.163	1.000	1	
51	180.000	27.895	1.50839	
52	297.607	1.000	1	
53	155.389	32.579	1.50839	
54	496.127	4.141	1	(ASP3)
55	712.002	27.982	1.50839	
56	65.481	4.652	1	
57	66.000	59.959	1.50839	
58	441.381	(WD)	1	

[0077]

[Table 11]

Aspherical Coefficients

Aspherical Coefficients of ASP4	
c=	1.04421E-03
κ=	0
A=	-2.65532E-08
B=	-4.16828E-13
C=	5.01741E-18
D=	-6.52068E-21
E=	7.82794E-25
F=	-6.18178E-29
Aspherical Coefficients of ASP1	
c=	-4.76234E-03
κ=	0.861651
A=	-7.84820E-09
B=	3.01423E-12
C=	9.70754E-17
D=	1.62617E-21
E=	-2.56672E-25
F=	1.42087E-29
Aspherical Coefficients of ASP2	
c=	-2.09084E-03
κ=	2.804972
A=	-8.77018E-09
B=	-4.80478E-13
C=	-3.02578E-18
D=	-2.74308E-21
E=	2.11317E-25
F=	-1.37915E-29
Aspherical Coefficients of ASP3	
c=	2.01561E-03
κ=	0
A=	5.23214E-10
B=	1.19414E-12
C=	-5.86228E-17
D=	1.24893E-21
E=	0
F=	0

[0078]

[Table 12]

Condition Corresponding Values for the Third Embodiment

(1)	$0.083 \le d/\{L \times (1 - N.A.)\} \le 0.207$
(2)	f1/L=0.123
(3)	-f2/L=0.047
(4)	f3/L=0.104
(5)	-f4/L=0.080
(6)	f5/L=0.110

f1= 145.982
f2= -56.252
f3= 123.837
f4= -94.933
f5= 131.432
L= 1191.307
d= 49.380
N.A.= 0.8~0.5

[0079]

Fig. 3 shows vertical aberrations of the projection optical system of the third embodiment. Fig. 10 shows horizontal aberrations (coma) in the tangential direction and the sagittal direction.

[0080]

As is clear from each aberration diagram, with respect to the projection optical system of the third embodiment, in the large exposure region overall, particularly distortion is preferably corrected, and other aberrations are also corrected in a well-balanced manner. Furthermore, even if both sides of the projection optical system of the third embodiment is telecentric, the maximum value of the numerical aperture is 0.8 which is large, and the effects of vignetting is less. Even when the numerical aperture is changed to be large, each aberration can be preferably corrected.

[0081]

(Fourth Embodiment)

The following explains a structure of a projection optical system according to a fourth embodiment. An exposure wavelength in this embodiment is also 248.4 nm. Fig. 11 is a cross-sectional view showing a lens structure of a projection optical system of the fourth embodiment. In Fig. 11, a projection optical system is constituted by, in order from a reticle R (object plane) as a first object, a first lens group G1 having a positive refractive power, a second lens group G2 having a negative refractive power, a third lens group G3 having a positive refractive power, a fourth lens group G4 having a negative refractive power, and a fifth lens group G5 having a positive refractive power.

[0082]

Furthermore, the projection optical system is made telecentric on both the reticle R (object plane) side and the wafer W (image plane) side as a second object.

[0083]

Furthermore, in the projection optical system of Fig. 11, on a near axis, a position Q in which a light beam parallel to the optical axis that enters the optical system PL from the wafer W side crosses the optical axis AX exists between the fourth and fifth lens groups G4 and G5, respectively, and the aperture stop AS having a variable mechanism is arranged on the wafer W side from the position Q. Because of this, the difference of vignetting on the entire surface of the exposure region on the wafer W can be minimized.

[0084]

In addition, the aspherical surface ASP1 is arranged within the fourth lens group G4, the aspherical surface ASP2 is arranged between the aspherical surface ASP1 and the aperture stop AS of the wafer W side, and the aspherical surface ASP3 is arranged between the aperture stop

AS within the fifth lens group G5 and the wafer W side. Furthermore, the aspherical surface ASP4 is arranged in the third lens group G3.

[0085]

Numerical values of the projection optical system of the fourth embodiment are listed in Table 13-16. Furthermore, in the same manner as in the projection optical system of the first embodiment, for example, fluorite can be used for a glass material.

[0086]

If the maximum value of the numerical aperture of the wafer W side of the projection optical system of the fourth embodiment is also 0.8, and the variable range of the numerical aperture is approximately 60% of the maximum value, the variable range of the numerical aperture according to the aperture stop AS is $0.5 \leq$ N. A. ≤ 0.8.

[0087]

[Table 13]

Numbers for the Fourth Embodiment

D0=	56.195
WD=	8.547
β=	1/4
Maximum N.A.=	0.8
Φ EX=	26.4
L=	1189.851

[0088]

[Table 14]

No.	r	d	n	
1	-281.019	13.000	1.50839	
2	316.929	8.609	1	
3	2500.000	26.225	1.50839	
4	-303.360	1.000	1	
5	804.062	24.227	1.50839	
6	-318.842	1.000	1	
7	354.459	29.152	1.50839	
8	-377.293	1.000	1	
9	263.543	17.000	1.50839	
10	199.659	6.604	1	
11	295.344	30.241	1.50839	
12	-307.153	1.074	1	
13	-2000.000	13.052	1.50839	
14	152.095	25.535	1	
15	-226.948	12.000	1.50839	
16	199.970	23.919	1	
17	-200.430	12.500	1.50839	
18	750.000	29.580	1	
19	-134.929	18.000	1.50839	
20	-423.324	6.957	1	
21	-286.676	29.399	1.50839	
22	-167.682	1.000	1	
23	∞	40.813	1.50839	
24	-266.938	1.000	1	
25	3220.051	42.890	1.50839	
26	-317.569	1.000	1	
27	302.026	48.170	1.50839	
28	-1518.815	1.000	1	(ASP4)
29	171.737	46.214	1.50839	
30	481.358	20.022	1	
31	458.364	20.729	1.50839	
32	121.840	46.884	1	
33	-203.076	12.000	1.50839	(ASP1)
34	185.000	45.147	1	
35	-121.196	12.850	1.50839	
36	∞	11.728	1	
37	-465.519	39.959	1.50839	(ASP2)
38	-170.031	4.118	1	
39	∞	8.882	1	(Q)
40	663.260	40.673	1.50839	
41	-392.224	0.000	1	
42	∞	9.244	1	(AS)
43	1492.727	49.719	1.50839	
44	-277.593	12.757	1	
45	-214.522	27.250	1.50839	
46	-282.481	10.000	1	
47	261.717	41.243	1.50839	
48	1246.120	1.000	1	
49	188.000	39.612	1.50839	
50	439.103	1.000	1	
51	178.000	29.125	1.50839	
52	307.599	1.000	1	
53	147.699	33.313	1.50839	
54	461.089	4.088	1	(ASP3)
55	612.505	24.500	1.50839	
56	65.463	6.105	1	
57	66.000	60.000	1.50839	
58	373.143	(WD)	1	

[0089]

[Table 15]

Aspherical Coefficients

Aspherical Coefficients of ASP4	
c=	-6.58408E-04
κ=	0
A=	-1.29700E-09
B=	-2.23515E-14
C=	2.71217E-19
D=	4.78605E-24
E=	0
F=	0
Aspherical Coefficients of ASP1	
c=	-4.92426E-03
κ=	1.140743
A=	-1.17013E-08
B=	2.95847E-12
C=	7.22796E-17
D=	3.50053E-21
E=	-4.73158E-25
F=	1.77468E-29
Aspherical Coefficients of ASP2	
c=	-2.14814E-03
κ=	-0.511241
A=	-2.90908E-09
B=	-3.82923E-13
C=	9.51818E-19
D=	-1.02058E-21
E=	7.38868E-26
F=	-3.11809E-30
Aspherical Coefficients of ASP3	
c=	2.16878E-03
κ=	0
A=	6.88715E-09
B=	8.36584E-13
C=	-4.26325E-17
D=	9.02955E-22
E=	0
F=	0

[0090]

[Table 16]

Condition Corresponding Values For the Fourth Embodiment

(1)	$0.084 \leq d/\{L \times (1-N.A.)\} \leq 0.208$
(2)	f1/L=0.125
(3)	-f2/L=0.047
(4)	f3/L=0.103
(5)	-f4/L=0.079
(6)	f5/L=0.109

f1= 145.857
f2= -55.987
f3= 122.578
f4= -93.819
f5= 130.011
L= 1189.851
d= 49.554
N.A.= 0.8~0.5

[0091]

Fig. 12 shows vertical aberrations of the projection optical system of the third embodiment. Fig. 13 shows horizontal aberrations (coma) in the tangential direction and the sagittal direction.

[0092]

As is clear from each aberration diagram, with respect to the projection optical system of the fourth embodiment, in the large exposure region overall, particularly distortion is preferably corrected, and other aberrations are also corrected in a well-balanced manner. Furthermore, even if both sides of the projection optical system of the fourth embodiment is telecentric, the maximum value of the numerical aperture is 0.8 which is large, and the effects of vignetting is less. Even when the numerical aperture is changed to be large, each aberration can be preferably corrected.

[0093]

Additionally, in the above-mentioned embodiments, an example of using light with a wavelength of 249.4 nm as an exposure light beam is shown, but this invention is not limited to

this. Needless to say, this invention can also be applied to the case when extreme ultraviolet light such as excimer laser light or the like of ArF (wavelength 193 nm), a g line (λ=wavelength 435.8 nm) of a mercury lamp, an i line (λ=wavelength 365.0 nm), or the like, and light of a ultraviolet region other than these are used. Furthermore, fluorite (CaF_2) or the like can also be used as a glass material.

[0094]

The following explains one example of an operation when a predetermined circuit pattern is formed on wafer by using the projection exposure apparatus of the above-mentioned embodiments with reference to a flowchart of Fig. 14. First, in step 1 of Fig. 14, a metal film is deposited on one lot of wafers. In step 2, a photoresist is coated on the metal film on the one lot of wafers. After that, in step 3, by using the projection exposure apparatus of Fig. 1 provided with the projection optical system PL of the first embodiment (Fig. 2), an image of a pattern on a mask is sequentially exposed and transferred onto each shot region on the one lot of wafers via the projection optical system PL. After that, in step 4, after a photoresist on the one lot of wafers is developed, in step 5, by etching the resist pattern on the one lot as a mask, a circuit pattern corresponding to a pattern on the reticle R is formed in each shot region on each wafer. After that, a device such as a semiconductor element or the like is manufactured by forming a circuit pattern of additional upper layers.

[0095]

At this time, in the projection optical system PL of this example, both sides are telecentric and the numerical aperture can be made large, so even if there is warping in the reticle R or warping in each wafer W to be exposed, a fine circuit pattern with high resolution is stably

formed on each wafer W. Furthermore, the exposure region of the projection optical system is large, so a large device can be manufactured with a good throughput.

[0096]

Additionally, this invention is not limited to the above-mentioned embodiments, but various structures can be obtained within the scope of the claims.

[0097]

[Effects of the Invention]

As described above, in the projection optical system as set forth in claim 1, even if the numerical aperture is variable, vignetting does not become too large, and both sides can be made telecentric. Furthermore, by using an aspherical surface, a large exposure region and a large numerical aperture can be obtained with a compact optical system.

[0098]

Furthermore, in the projection optical system as set forth in claim 2, by arranging the aperture stop between the crossing position Q and the second object, the effects of the above-mentioned vignetting can be minimized.

[0099]

Additionally, in the projection optical system as set forth in claim 3, the refractive power of the peripheral part of the aspherical surface is increased or reduced compared to the refractive power in the vicinity of the optical axis. Because of this, the spherical aberration generated in the positive lens can be preferably corrected.

[0100]

Furthermore, in the projection optical system as set forth in claim 4, even if the numerical aperture is variable, vignetting does not become too large, and both sides can be made

telecentric. The refractive power of the peripheral part of the aspherical surface is increased or reduced compared to the refractive power in the vicinity of the optical axis. Because of this, the spherical aberration generated in the positive lens can be preferably corrected.

[0101]

Furthermore, in the projection optical system as set forth in claim 5, the aspherical surface is arranged in the first lens group G1, so mainly distortion aberration can be corrected.

[0102]

In addition, in the projection optical system as set forth in claim 6, the aspherical surface is arranged in the second lens group G2, so mainly aberration of the entrance pupil (shifting of the entrance pupil corresponding to an object height) can be minimized.

[0103]

Furthermore, in the projection optical system as set forth in claim 7, by arranging the aspherical surface in the third lens group G3, mainly coma can be corrected.

[0104]

Additionally, in the projection optical system as set forth in claim 8, the condition equations (2)-(6) can be satisfied, so various aberrations, particularly, spherical aberration and distortion can be preferably corrected. Furthermore, enlargement of the optical system can be prevented.

[0105]

Additionally, in the projection exposure apparatus as set forth in claim 9, a projection optical system with both side telecentricity which can obtain a high numerical aperture is provided, so even if there is warping in a mask or a substrate, there is an advantage that a mask pattern image can be transferred with a high resolution onto a substrate. Furthermore, the

projection optical system of this invention has an exposure region, so an extremely fine circuit pattern can be formed in a wide exposure region on the substrate.

[0106]

Furthermore, the method of manufacturing the semiconductor device as set forth in claim 10, even when there is warping in a mask or substrate, a device with a high performance capability can be manufactured with high resolution.

[Brief Description of the Drawings]

Fig. 1 is a schematic structural diagram showing a projection exposure device using a projection optical system of a first embodiment of this invention.

Fig. 2 is a lens cross-sectional view showing the projection optical system of the first embodiment.

Fig. 3 is a vertical aberration diagram of the projection optical system of the first embodiment.

Fig. 4 is a horizontal aberration diagram of the projection optical system of the first embodiment.

Fig. 5 is a lens cross-sectional view showing the projection optical system of the second embodiment.

Fig. 6 is a vertical aberration diagram of the projection optical system of the second embodiment.

Fig. 7 is a horizontal aberration diagram of the projection optical system of the second embodiment.

Fig. 8 is a lens cross-sectional view showing a projection optical system of a third embodiment of this invention.

Fig. 9 is a vertical aberration diagram of the projection optical system of the third embodiment.

Fig. 10 is a horizontal aberration diagram of the projection optical system of the third embodiment.

Fig. 11 is a lens cross-sectional view showing a projection optical system of a fourth embodiment.

Fig. 12 is a vertical aberration diagram of the projection optical system of the fourth embodiment.

Fig. 13 is a horizontal aberration diagram of the projection optical system of the fourth embodiment.

Fig. 14 is a flowchart showing one example of an operation when a predetermined circuit pattern is formed by using the projection optical system according to the embodiments of this invention.

[Explanation of the Symbols]

R	Reticle (first object)
PL	Projection optical system
W	Wafer (second object)
F1	First lens group
F2	Second lens group
G3	Third lens group
G4	Fourth lens group
G5	Fifth lens group
AS	Aperture stop

ASP1-4	Aspherical surface
Q	Crossing position

[Document]

[Abstract]

[Problem]

To provide a projection optical system of which both sides are telecentric, having a large numerical aperture and a wide projection region and having corrected various aberrations.

[Solving Means]

A projection optical system PL which projects an image of a pattern on a first object R onto a second object W, in order from the first object side R, comprising:

a negative fourth lens group G4 having a positive first lens group G1, a negative second lens group G2, a positive third lens group G3, and an aspherical surface ASP 1, and

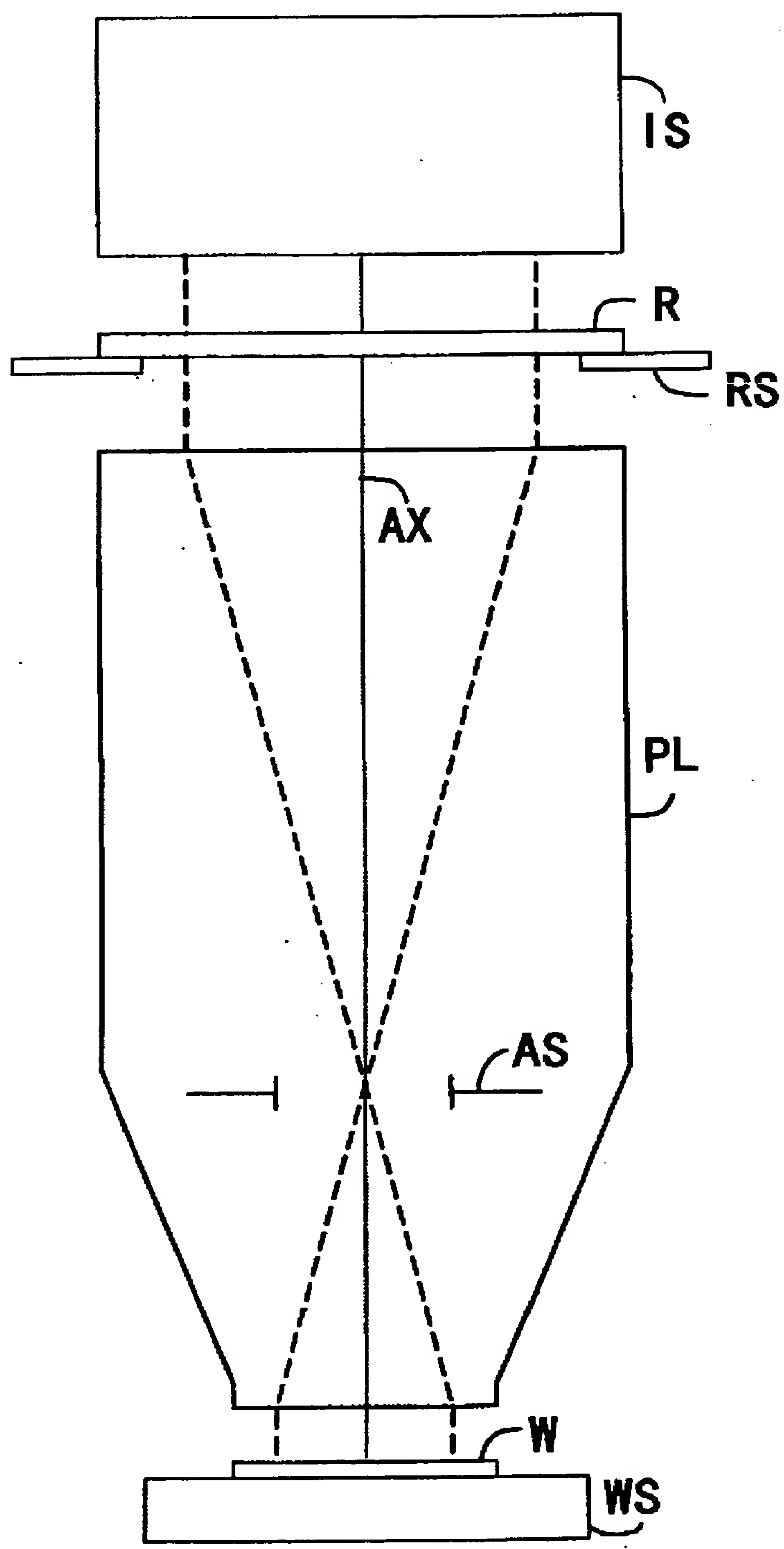
a positive fifth lens group G5 having an aspherical surface ASP 3 and an aperture stop AS,

wherein on a near axis, a position Q in which a light beam that enters the projection optical system parallel to an optical axis of the projection optical system from the second object W side crosses the optical axis is between the fourth and fifth lens groups G4 and G5, the fourth or fifth lens group has an aspherical surface ASP2, and a predetermined condition is satisfied.

[Selected Figure] Fig. 2

【書類名】 図面

【図1】



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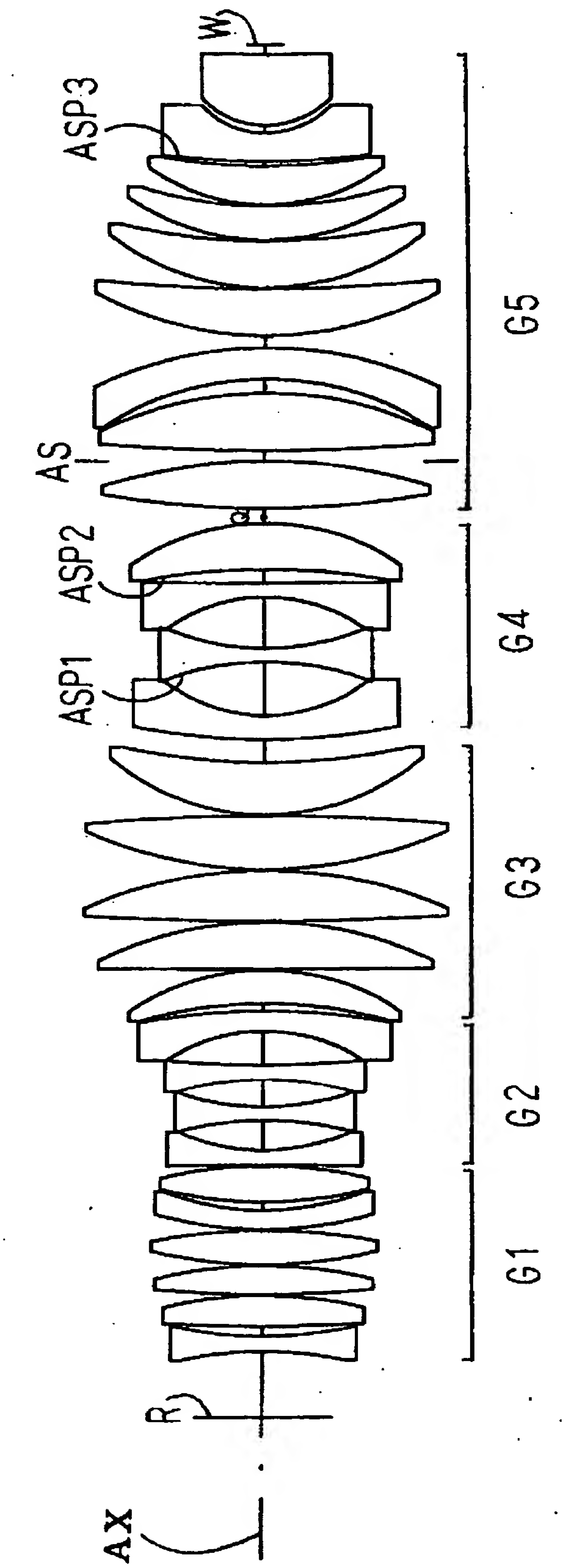

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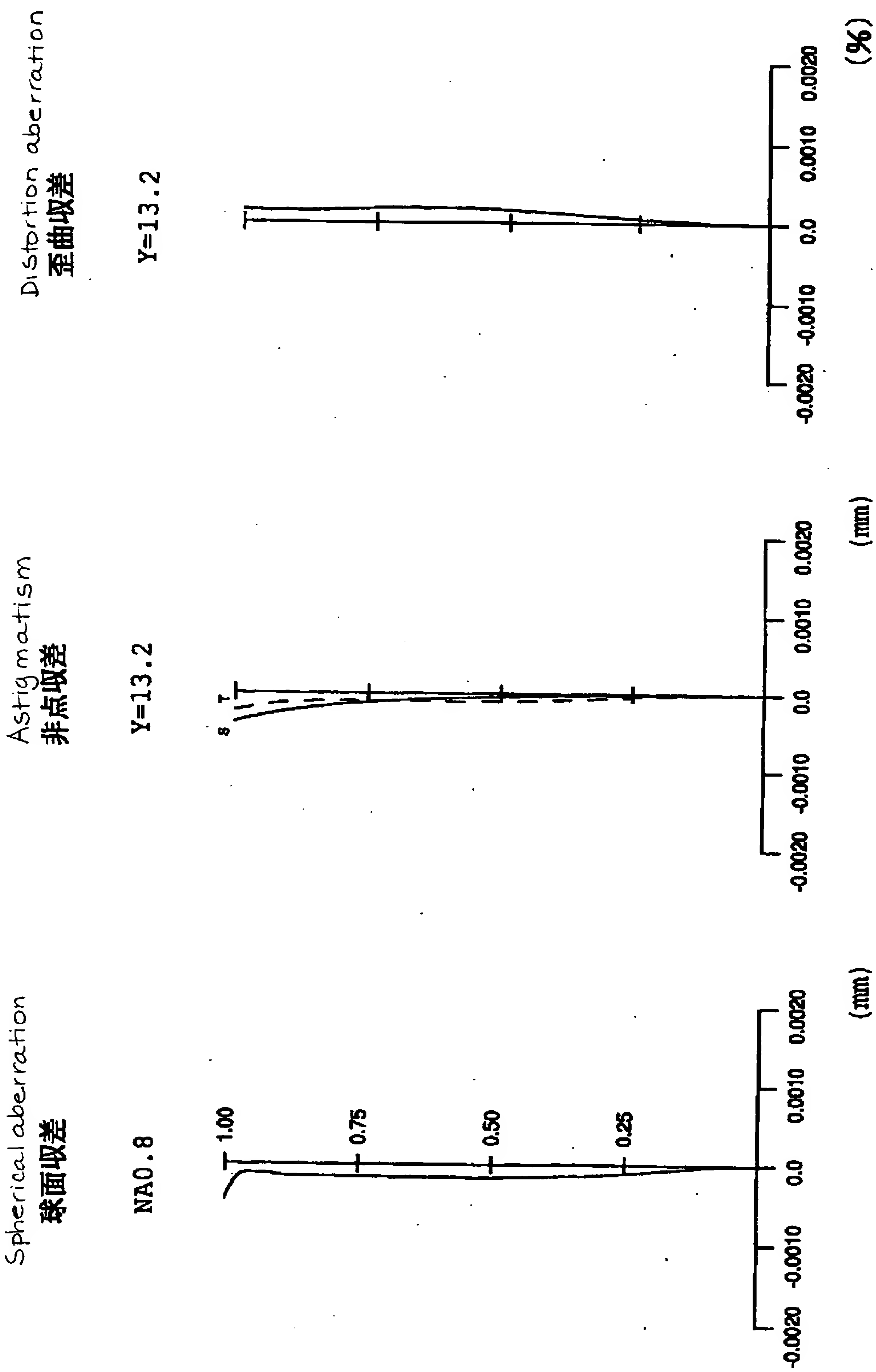
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非点収差
Y=13.2
T
S
(mm)
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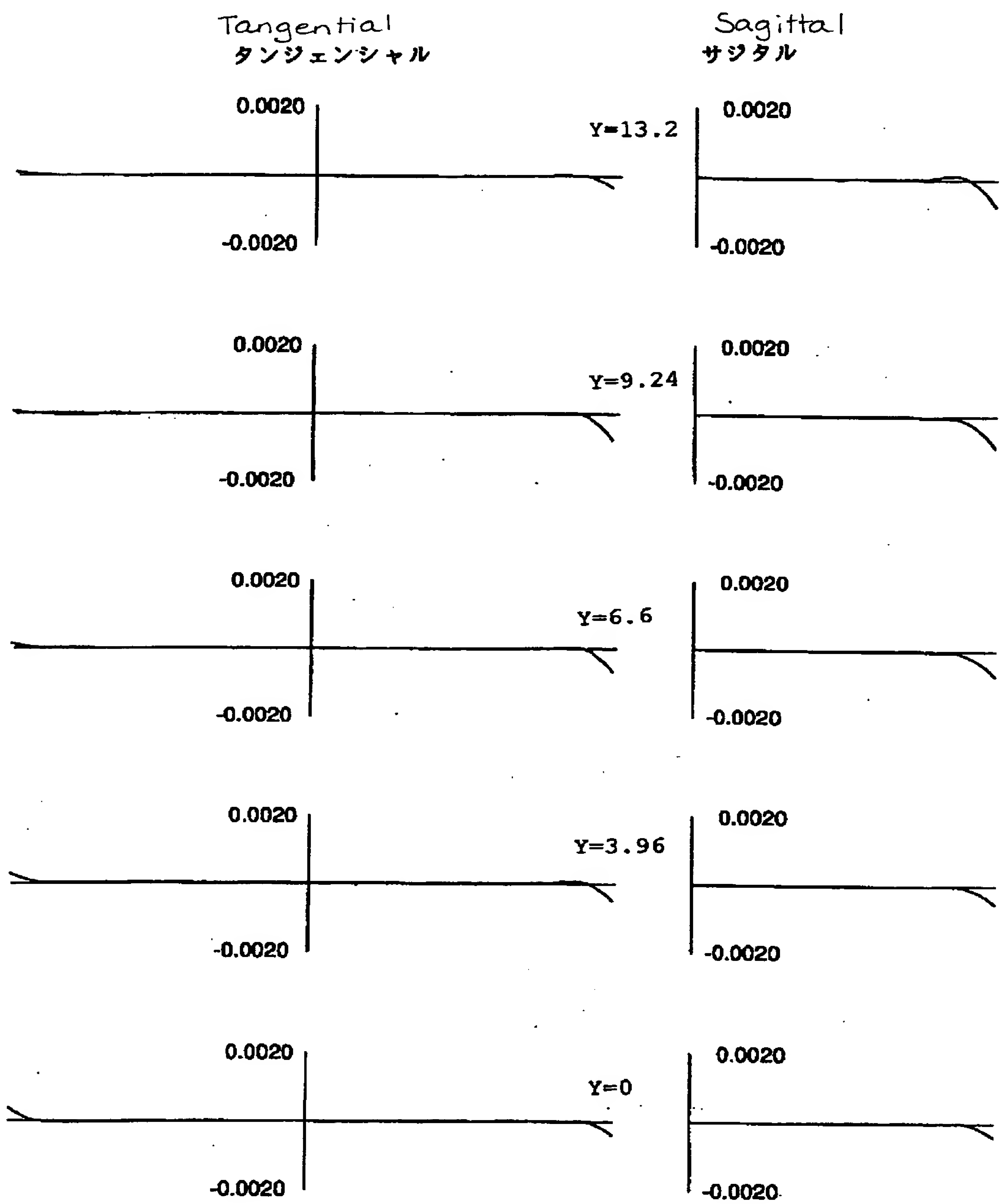
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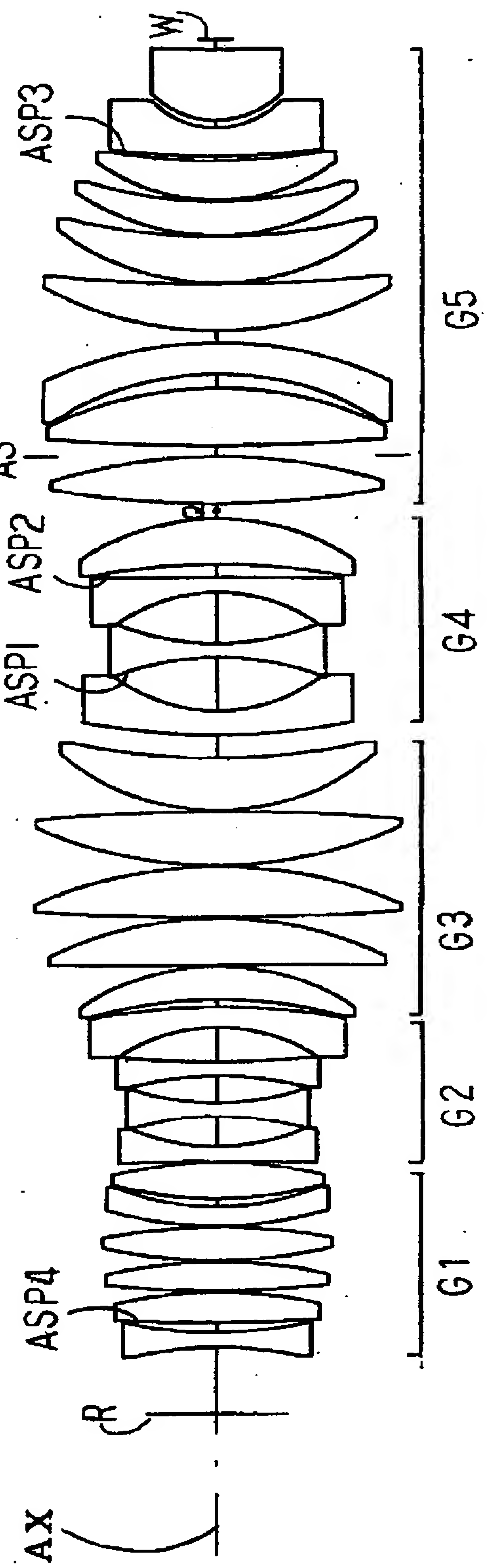

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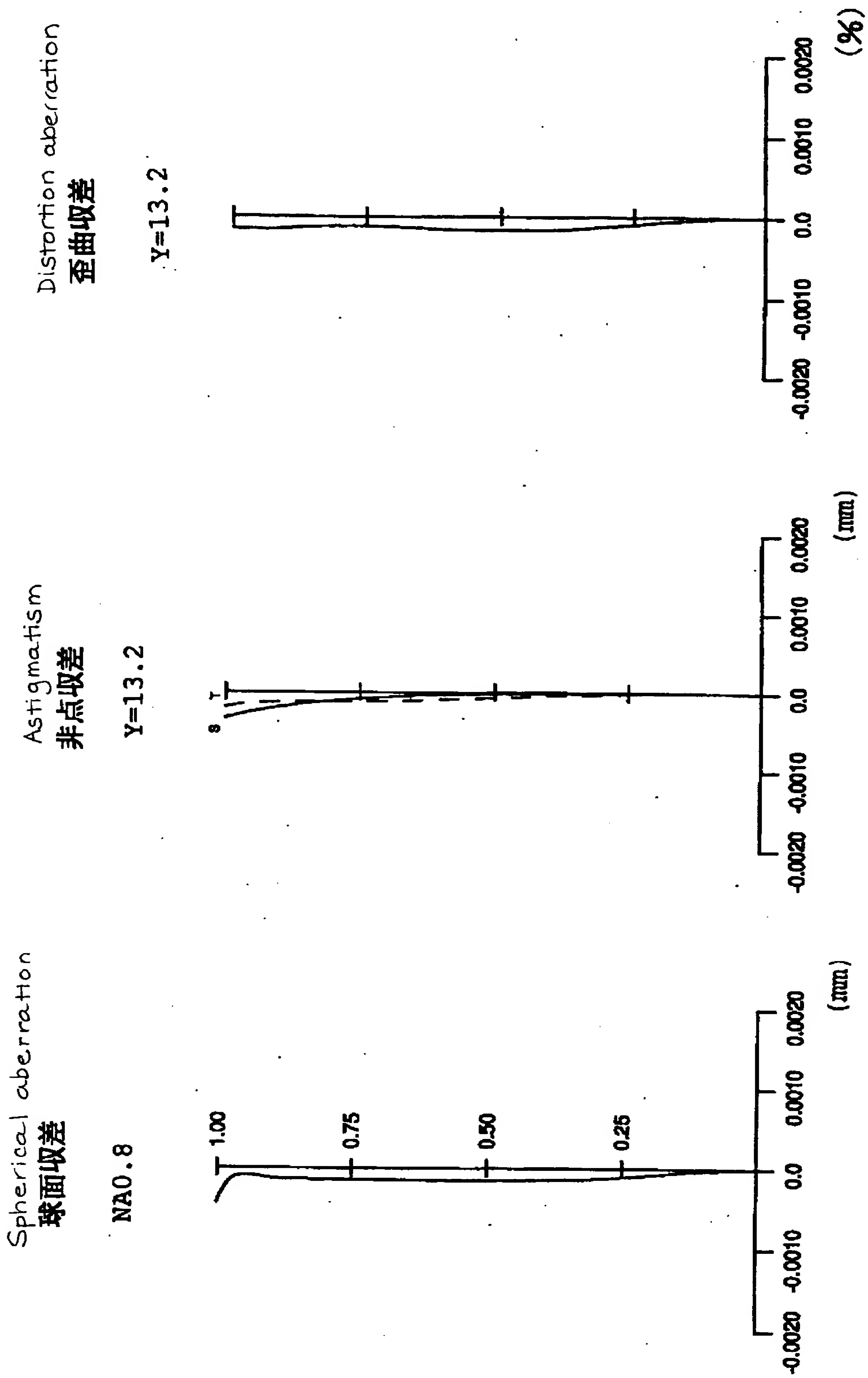
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S
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0.0020
(mm)
Spherical aberration
球面収差
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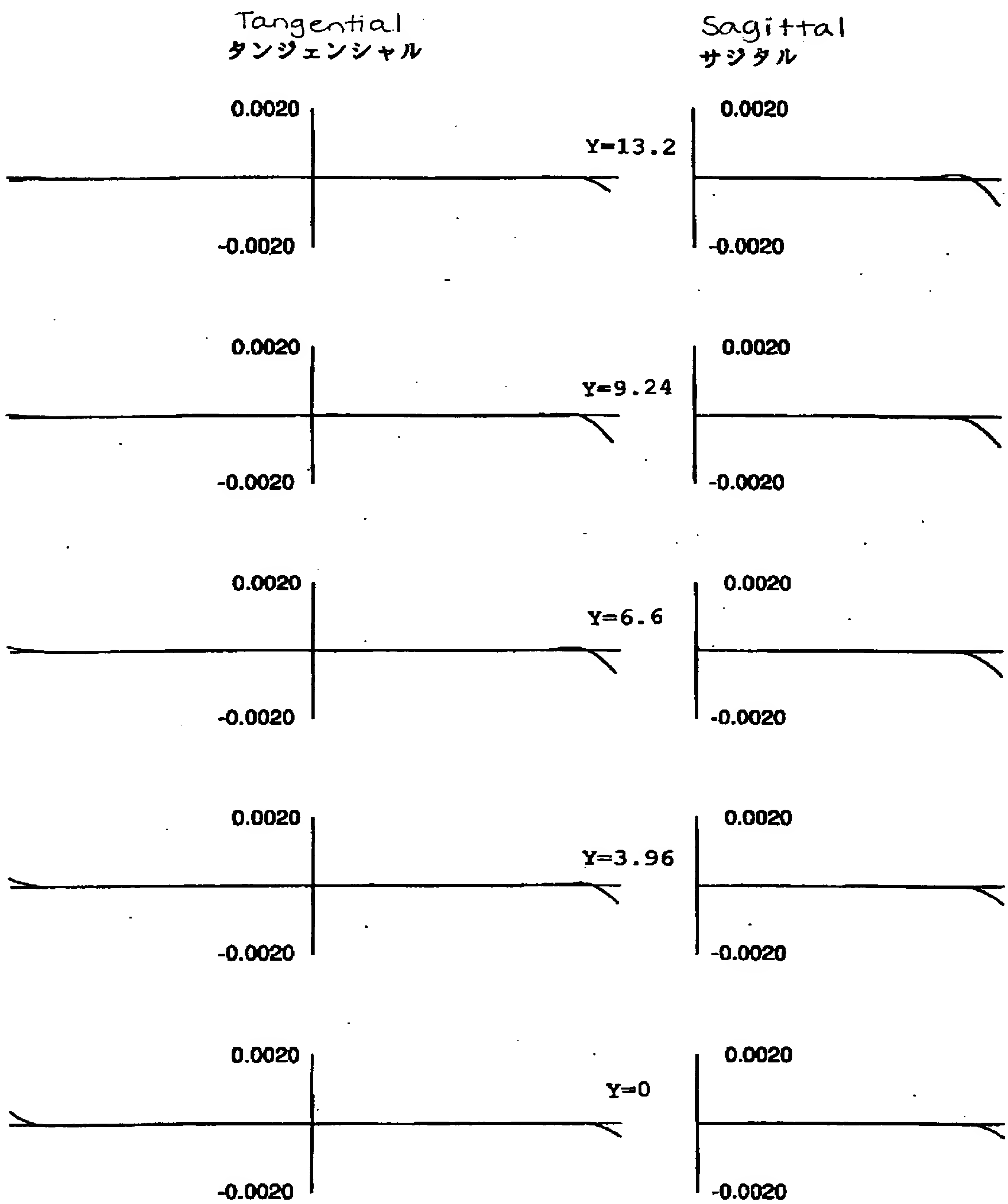
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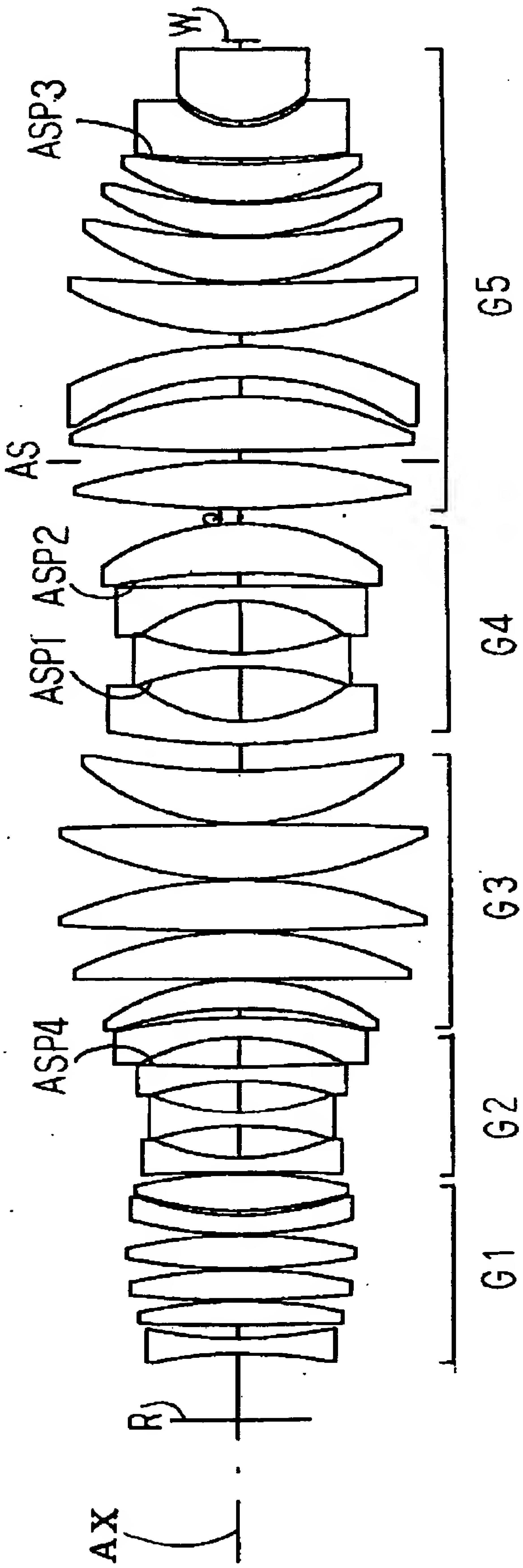

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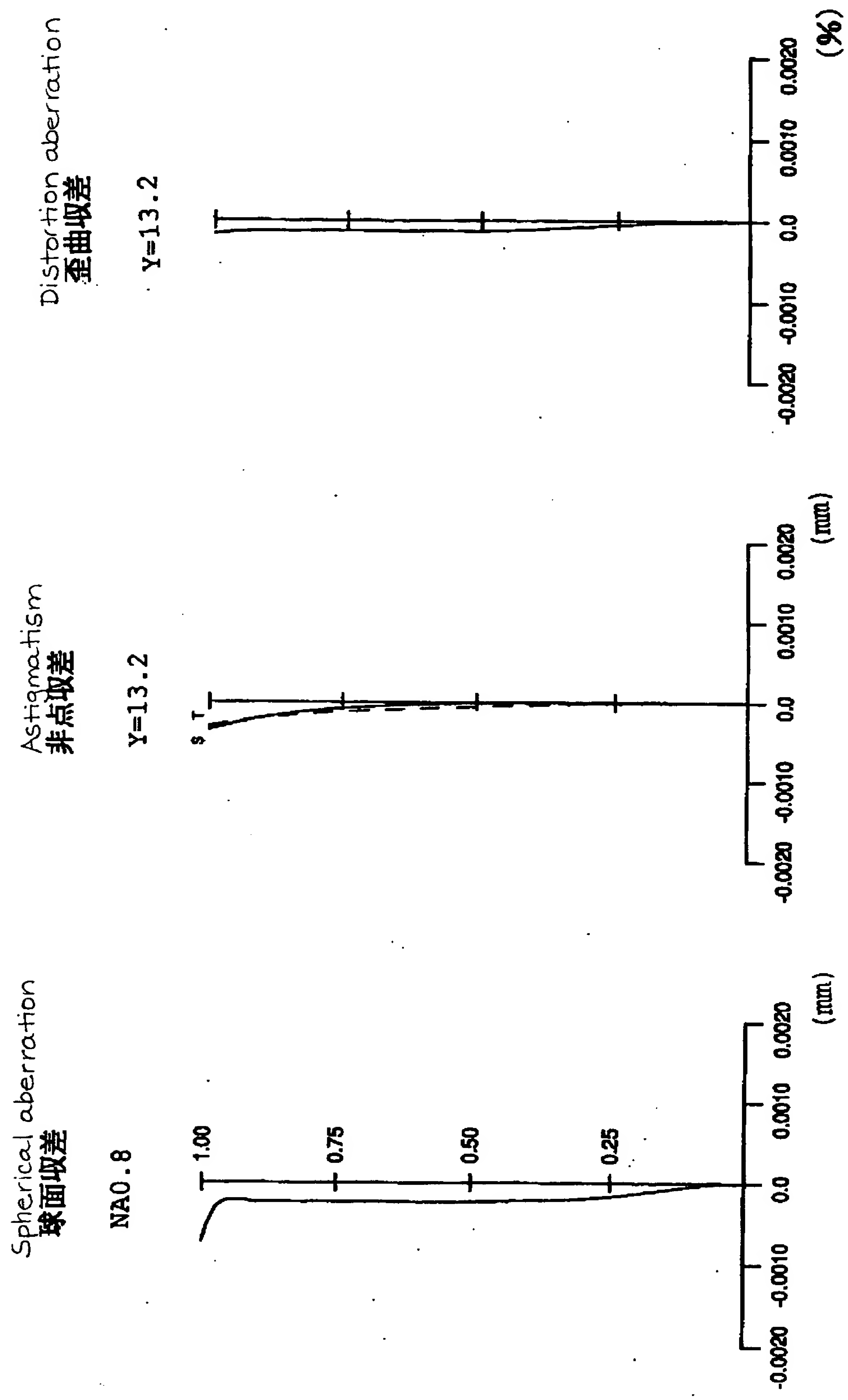
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(%)
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Y=13.2
S
T
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(mm)
Spherical aberration
球面収差
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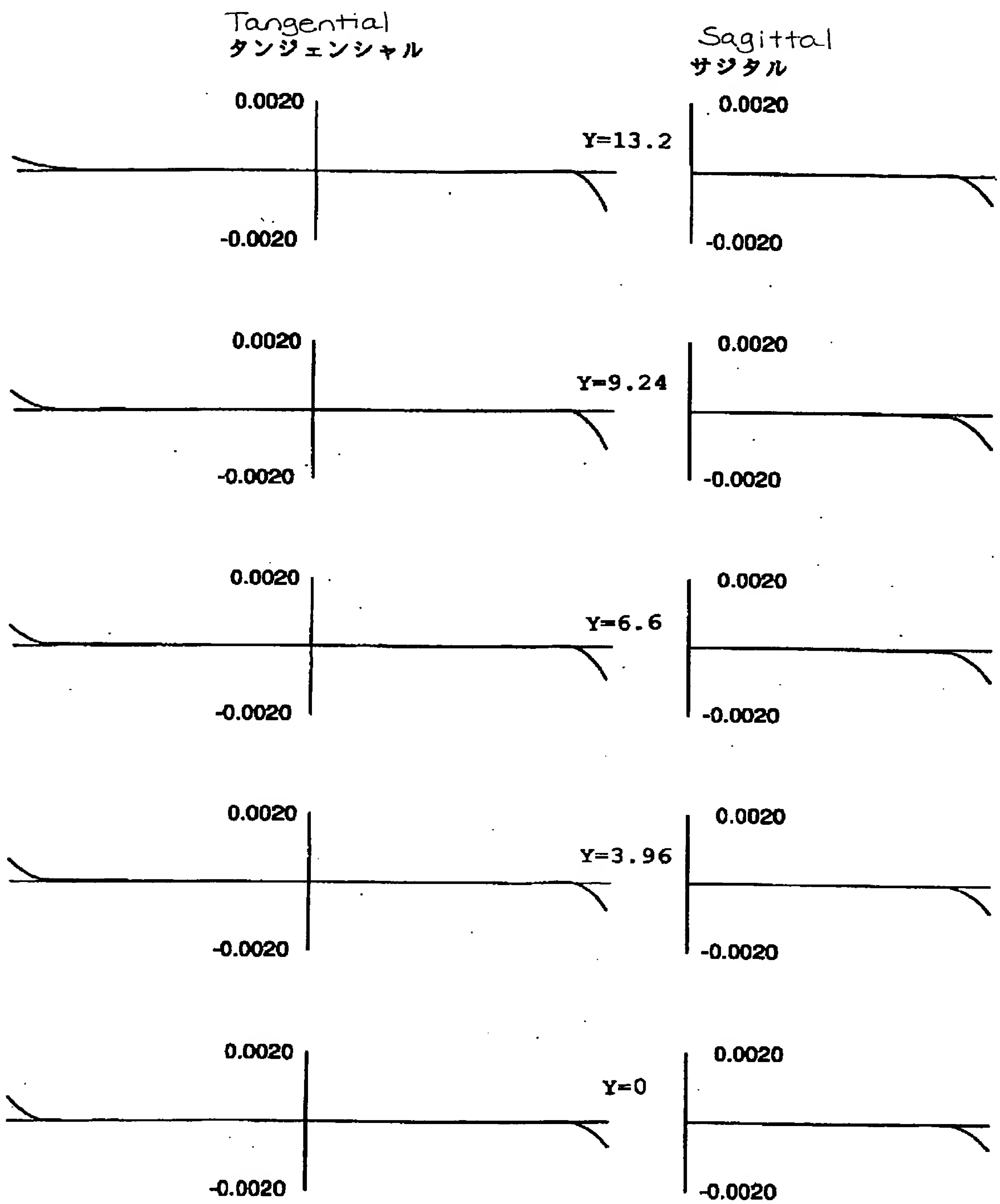
(mm)

【図１０】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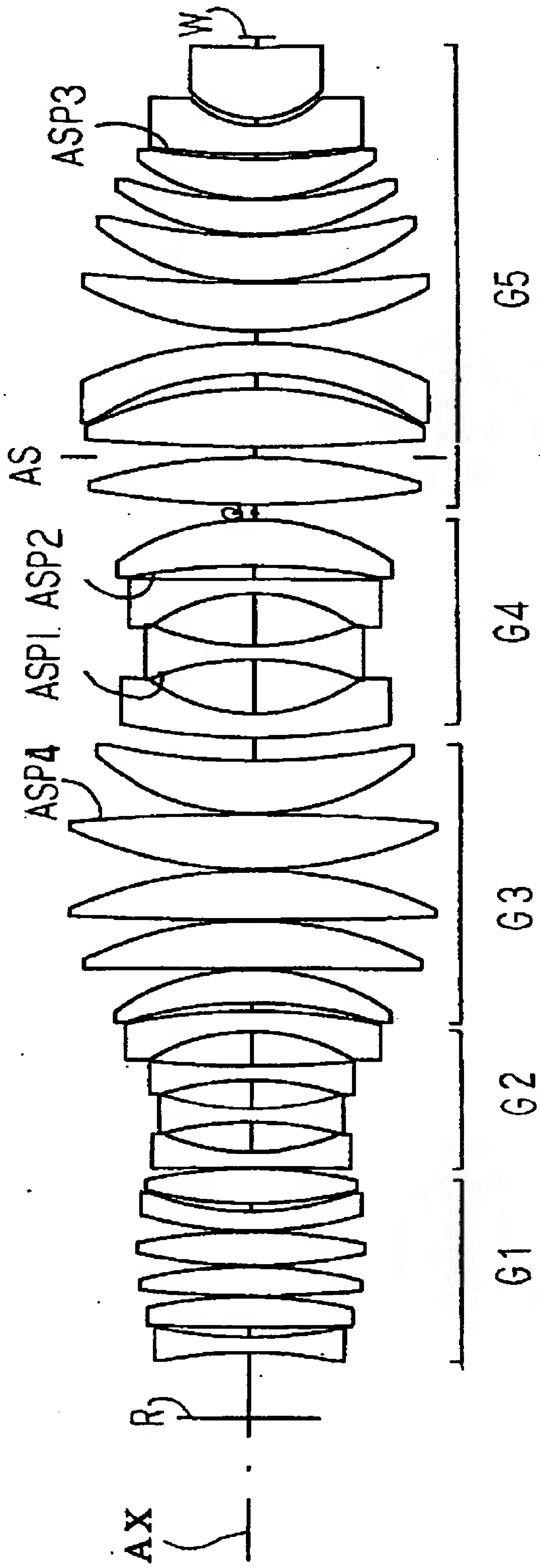
【図１１】



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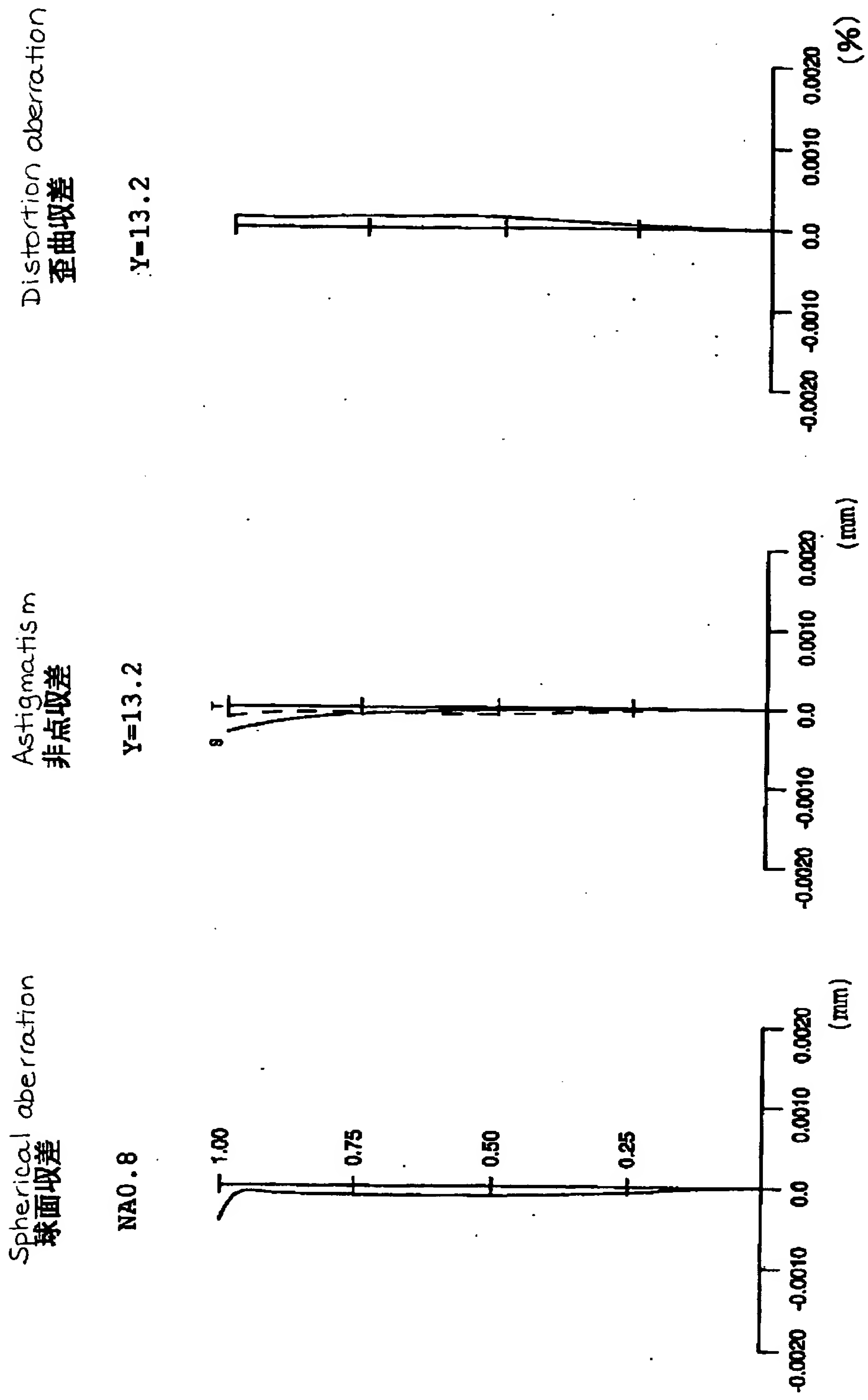
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Astigmatism
非点収差
Y=13.2
T
S
(mm)
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0.0010
0.0
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-0.0020
Spherical aberration
球面収差
NA0.8
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(mm)
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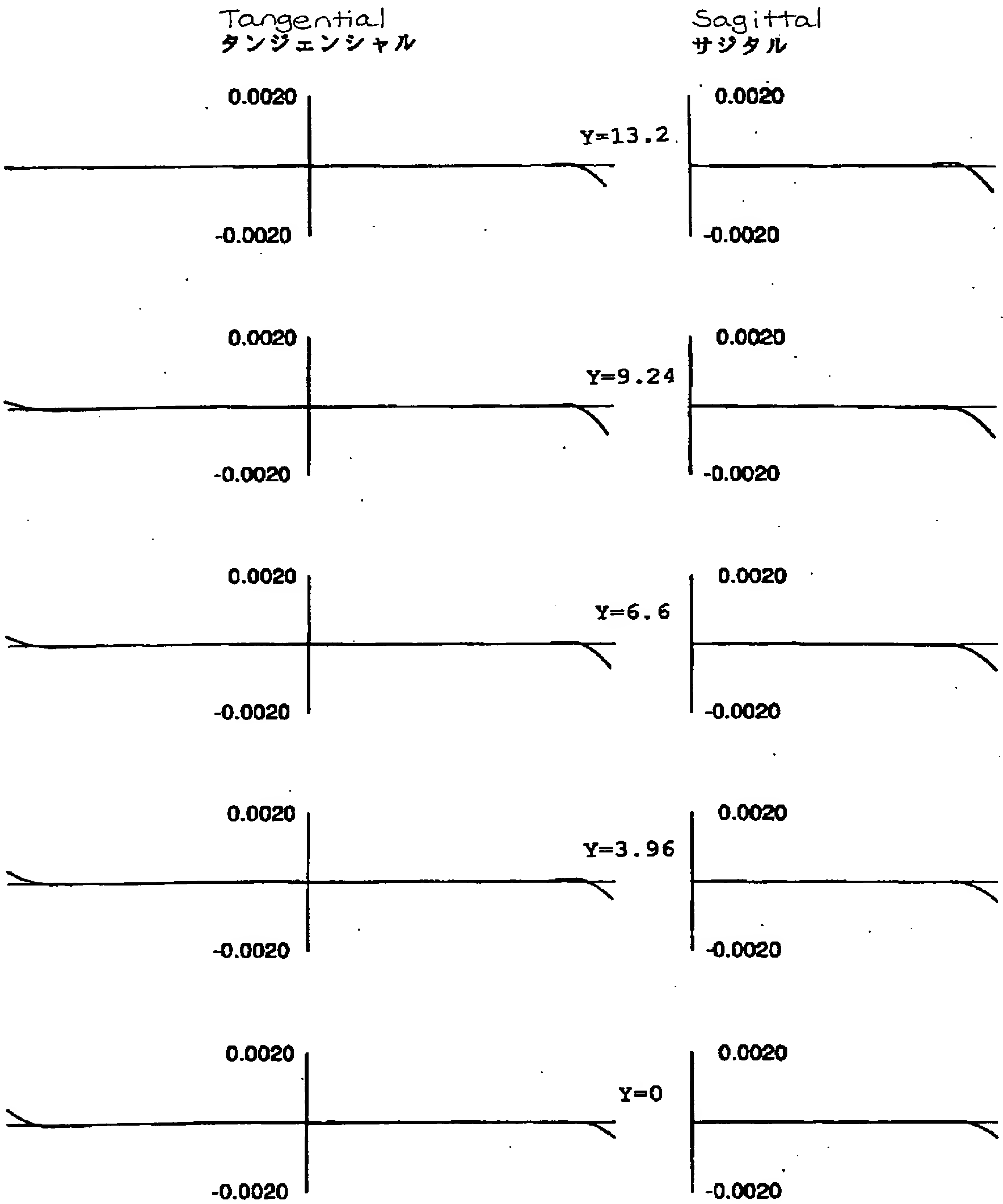
【図１３】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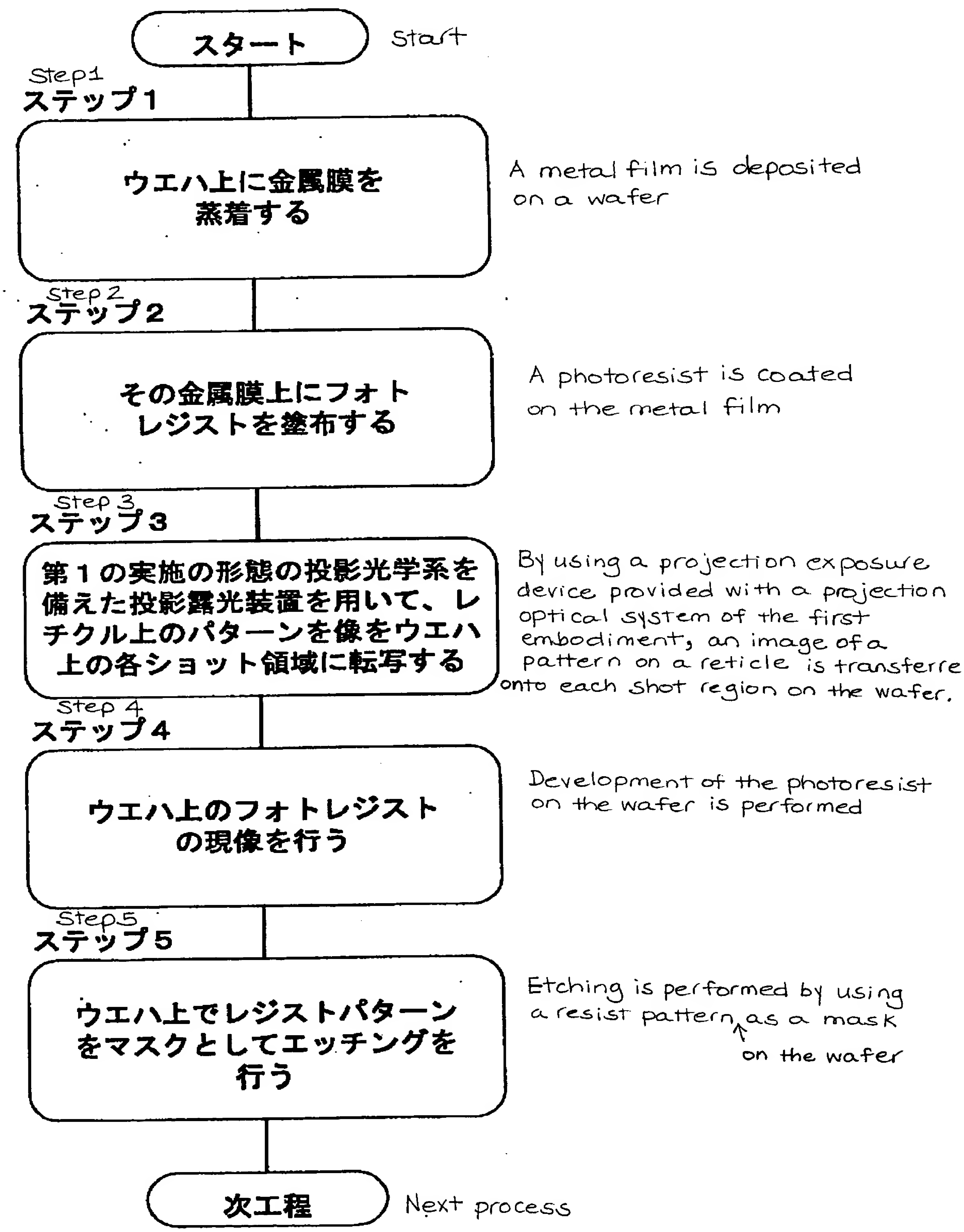
スタート
Start
Step1
ステップ１
ウエハ上に金属膜を蒸着する
A metal film is deposited on a wafer
Step 2
ステップ２
その金属膜上にフォトレジストを塗布する
A photoresist is coated on the metal film
Step 3
ステップ３
第１の実施の形態の投影光学系を備えた投影露光装置を用いて、レチクル上のパターンを像をウエハ上の各ショット領域に転写する
By using a projection exposure device provided with a projection optical system of the first embodiment, an image of a pattern on a reticle is transferre onto each shot region on the wafer.
Step 4
ステップ４
ウエハ上のフォトレジストの現像を行う
Development of the photoresist on the wafer is performed
Step5
ステップ５
ウエハ上でレジストパターンをマスクとしてエッチングを行う
Etching is performed by using a resist pattern as a mask
on the wafer
次工程
Next process